lighting and general supply feeders, and the current taken by a rotary converter. The last-named machine is motored from the outers of the lighting bus-bars, and, on the alternating-current side, in conjunction with transformers, supplies alternating current for transmission to distant points of the lighting system. The pressure readings show the voltage across the outers of the lighting bus-bars, and the voltage between each outer and the neutral of pilot wires, run to the central point of the lighting load.

74. Steam Plant and Shift Report.—In order to keep a record of the operation of the steam plant in the generating station, one column of the log sheet is allotted to each of the four boilers, and ticks in the proper columns indicate which boilers are kept under steam throughout the day. The following columns show the variations of the boiler steam pressure, the hours during which the steam-driven and electrically driven boiler feed-pumps are working, and the temperature of the feedwater supplied from economizers 1 and 2. For the condensers, the vacuum is given in the equivalent inches of mercury, and the temperatures, in degrees Fahrenheit, of the circulating-water inlet, circulating-water outlet, and the air-pump discharge. The variation of these quantities with the variation of load throughout the day may be studied with advantage. The remarks under the heading of Shift Report show the times at which the generators are started up or shut down and when the switches are opened or shut.

75. Summary of Daily Results.—The section of the log sheet comprising the summary of the daily results is usually entered up by the third, or evening, shift engineer, and its main purpose is self-explanatory. Records are kept of the units generated by each generator, units used on works, and of the units sent out on the various feeders. If desired, the meter readings of the separate watt-hour meters may be entered on the daily log sheet, but otherwise a separate meter book may be kept. The records of maximum load, and of the coal and water used, are clear from the respective headings and the items entered thereunder. A space is reserved at the bottom of the sheet on which to enter the results, daily or weekly as the case may be, of the Board of Trade tests of the traction system.

TRAMWAY TRACKS

TRACK WORK

RAILS AND RAIL ADJUSTMENTS

PRELIMINARY CONSIDERATIONS

1. Necessity for Substantial Construction.—The track on which electric tramcars are to be run must be very substantially constructed. The car wheels drive the car by their reaction on the rails and cause much greater wear and tear than if the cars were hauled by a moving cable or by horses, because the rails are subjected to a grinding action whenever the wheels fail to grip them, and slipping occurs. In addition to this, the driving motors and control gear increase the weight of the car, and consequently the pounding which goes on at rail joints, points, and crossings. The permanent way as constructed for horse tramways was altogether too light for the heavy cars and the rapid acceleration introduced by electric traction, and the track as constructed to-day is as substantial as for main-line steam railways.

2. Gauge.—By the gauge of the track is meant the width between the rails, measured from the outer side of the groove in one rail to the outer side of the groove in the other rail, as shown at *a* in Fig. 1.

The greater number of tramway companies in Great Britain have adopted either the broad or the narrow gauge, the former

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being 4 feet $8\frac{1}{2}$ inches and the latter 3 feet 6 inches. An important exception to this is the Glasgow tramways, where the gauge is 4 feet $7\frac{3}{4}$ inches, this width being adopted to allow the railway wagons in connection with the large shipyards to use the tram lines. As the tram lines were extended and new systems constructed in the neighbourhood this gauge was perpetuated. In Great Britain, approximately 50 per cent. of the tramways have adopted the broad gauge, 33 per cent. the narrow gauge, 5 per cent. a gauge of 4 feet $7\frac{3}{4}$ inches, and 7 per cent. a gauge of 4 feet 9 inches, the remaining 5 per cent. having odd dimensions.

The broad gauge is preferable to the narrow gauge, owing to the increased space available for fitting the motors, and also on account of the increased stability given to the car, this point being of special importance where cars with covered top decks

FIG. 1

are in use. The reasons for adopting a narrow gauge is to allow of more clearance on narrow streets when passing standing vehicles, and to reduce the amount of paving to be maintained by the tramway authority, which comprises all the paving between the rails, including the centre way, and an additional 18 inches beyond the outside rails.

3. Single and Double Tracks.—The question as to whether single or double track should be laid depends on the traffic to be expected and also on the width of the roadway. With a sufficient number of passing places, about a 5-minute service can be efficiently maintained on a single track, but there is always present the danger of collisions taking place, especially in foggy weather. Where the roadway is narrow and the cost of widening it prohibitive, a single track is sometimes put down for a service quicker than one car each way every 5 minutes, because if double track were put down with insufficient room

for a cart to stand at the side of the road, both the running of the cars and the ordinary traffic would be seriously interfered with. The two tracks of a double-track system must be laid such a distance apart as to give at least 15 inches clearance between the cars.

The position of the passing places, or turnouts, requires careful consideration. They must be so placed that the driver has a clear view of the whole of the stretch of single track in front of him, or if this is impossible, owing to bends in the road, electric signals must be fitted.

SPECIFICATION OF STEEL FOR RAILS

4. Composition of Rails.—Tramway rails are made of mild steel, that is, steel with low percentages of carbon, manganese, silicon, phosphorus, and sulphur. The percentages of carbon and silicon have a marked effect on the hardness of the rail. If the percentages of these elements are too small, the rail will be soft and the wearing qualities poor; if too high, the rail will be brittle. The following are the percentages of the various elements recommended by the Engineering Standards Committee: Steel suitable for rails should contain ·40 to ·55 per cent. of carbon, ·7 to 1·0 per cent. of manganese, and not more than ·10 per cent. of silicon, ·08 per cent. of phosphorus, and ·08 per cent. of sulphur.

5. Effects Produced by the Various Elements.—The effects produced by the various elements in steel are shown in Table I. It will be noted that the percentage of manganese is relatively high; this gives a rail which is hard, yet ductile, and of good wearing qualities.

6. Sandberg Rails.—It has been found that rails containing a high percentage of silicon give excellent wearing results, but have the disadvantage of being very brittle. Mr. C. P. Sandberg, who has made a special study of this subject, found that the effect of silicon, when added, is entirely different from the effect of silicon left in from the pig iron. When the percentage of silicon left in exceeds the amounts specified in Table I, it causes

brittleness, but when the silicon is first eliminated, and a certain known quantity is afterwards added, the effect is to toughen the steel. Rails made to the Sandberg specification, containing 5 to 10 times the amount of silicon generally found in Bessemer

TABLE I

EFFECTS PRODUCED BY VARIOUS ELEMENTS IN STEEL

Element	Purpose for Which Element is Required	Variation of Percentage Present	Effect Produced if Present in Excess
Carbon . .	To give requisite amount of strength and hardness	·4 to ·7	Makes the metal brittle, and liable to fracture under shock or large change of temperature
Manganese .	To give ductility	·70 to 1·0	Greatly reduces conductivity, and makes metal too malleable
Silicon . . .	To make metal dense and compact, and give fluidity when molten	·066 to ·25	Makes metal brittle
Phosphorus .	Undesirable, but costly to eliminate	·05 to ·11	Makes metal brittle
Sulphur . .	Undesirable, but costly to eliminate	·05 to ·07	Makes metal seamy

or open-hearth steel, have been tried on several railways and tramways, and reports which have recently been published show a life twice that of ordinary rails. The cost of manufacture is, however, greater than for ordinary rails.

RAIL SECTIONS

7. British Standard Sections.—The section of tramway rail adopted in Great Britain is the grooved girder rail shown in Fig. 2, where *a* is the flange, *b* the web, *c* the tread, *d* the check, and *e* the groove. Five different sections of this have been standardized by the Engineering Standards Committee for

straight-line work, and five for curve work, the latter varying from the former in the width and depth of the groove. For straight-line work the groove is $1\frac{1}{8}$ inches wide by $1\frac{1}{8}$ inches deep, and for curve work $1\frac{1}{4}$ inches wide and $1\frac{1}{4}$ inches deep. The various sections are known as British Standard No. 1, No. 2, etc., usually abbreviated to B.S. No. 1, etc., the curve sections having the letter *c* after the number. The weights of the various sections, with the depths of the sections and the widths of the flanges, are given in Table II.

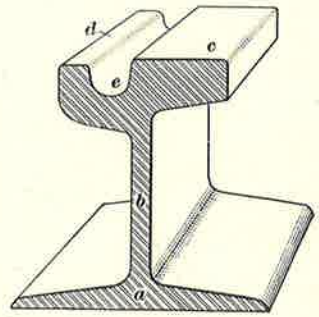


FIG. 2

TABLE II

STANDARD TRAMWAY-RAIL SECTIONS AND WEIGHTS

British Standard Rail Section Number	Weight Pounds Per Yard	Depth of Section Inches	Width of Flange Inches	British Standard Rail Section Number	Weight Pounds Per Yard	Depth of Section Inches	Width of Flange Inches
1	90	$6\frac{1}{2}$	$6\frac{1}{2}$	3*c*	106	$6\frac{1}{2}$	7
1*c*	96	$6\frac{1}{2}$	$6\frac{1}{2}$	4	105	7	7
2	95	$6\frac{1}{2}$	7	4*c*	111	7	7
2*c*	101	$6\frac{1}{2}$	7	5	110	7	7
3	100	$6\frac{1}{2}$	7	5*c*	116	7	7

8. Standard templates are in the hands of the different makers, so that rails to the weights and dimensions given can always be procured by giving the section number. This standardizing of rail sections has been a great boon to the rail manufacturers as well as a convenience to the users, as it reduces the number of rolls which have to be kept in stock and also the cost of production.

The standard sections B.S. No. 3 and No. 3*c* are shown in Fig. 3 (*a*) and (*b*), most of the principal dimensions being given. For a complete list of dimensions, including those of the various fillets and corners, the report of the Engineering Standards

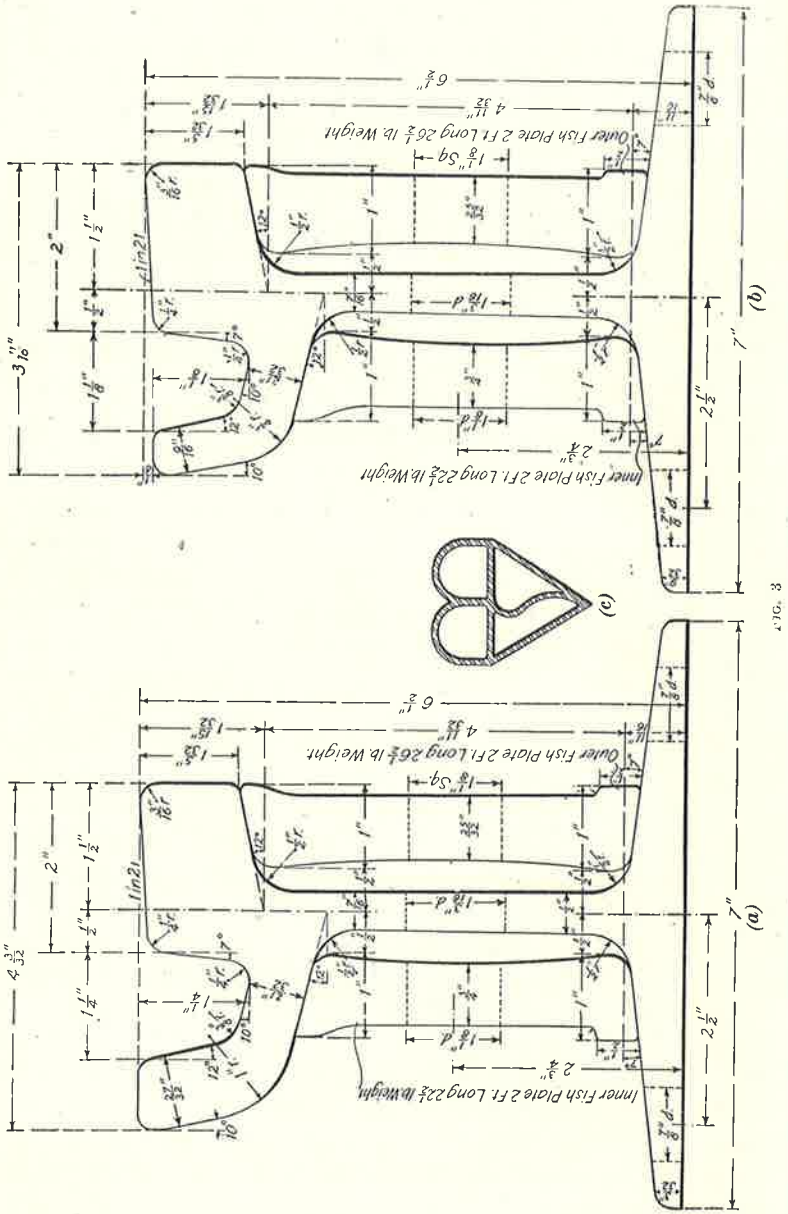


FIG. 3

Committee should be consulted. All standard rails are branded as shown in Fig. 3 (*c*), and have, in addition, the section number, the weight per yard, the names of the maker and purchaser, and the date of supply. The rails are usually supplied in 35-, 45-, and 60-foot lengths.

9. Cross-Section and Weight of Rails.—Rails are always referred to by their weight, in pounds per yard. Thus, a rail weighing 60 pounds per yard is known as a 60-pound rail ; one weighing 80 pounds per yard, as an 80-pound rail ; and so on. The weight, in pounds per yard, divided by 10 gives approximately the cross-sectional area, in square inches. For example, an 80-pound rail would have a cross-sectional area of $\frac{80}{10} = 8$ square inches.

Let A = area of rail section, in square inches ;
W_y = weight of rail, in pounds per yard.

Then, $$A = \frac{W_y}{10} \qquad (1)$$

Rule I.—*To find the area of cross-section of a rail, in square inches, divide the weight, in pounds per yard, by 10.*

To find the weight of rails, neglecting tie-bars, fish-plates, bolts, etc., required per mile of single track, the following simple formula may be used :

Let W_t = weight of rails, in tons, for 1 mile of single track ;
W_y = weight of rail, in pounds per yard.

Then, $$W_t = 1{\cdot}57\ W_y \qquad (2)$$

Rule II.—*The number of tons weight of rails required for 1 mile of single track is equal to 1·57 times the weight of the rail per yard, in pounds.*

10. Wheels and Rails With Bevelled Tread. — It has been found advantageous to make the treads of the car wheels slightly conical ; that is, the diameter of tread next to the flange is larger than its diameter at the outside edge. This is done to allow the car to adjust itself on the track when the two wheels on the same axle are not exactly of the same size. This construction probably performs its function when there is no greater difference in the wheels than is found on two wheels of the same make just as they come from the foundry ; this difference

is, as a rule, not more than $\frac{3}{8}$ inch in the circumference. The bevelled tread cannot, however, be expected to have much equalizing effect in cases where the difference in diameter of the two wheels is $\frac{3}{8}$ or $\frac{1}{2}$ inch.

It will be observed that, in order to give a good traction surface between the wheels and the rail, the rail tread is bevelled to suit the wheel, the amount of slope or bevel being 1 in 21, as indicated in Fig. 3 (*a*) and (*b*).

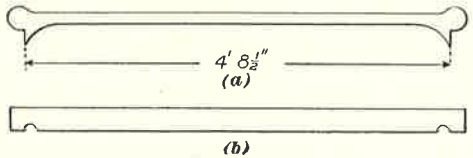


FIG. 4

11. Rail Grooves and Wheel Flanges.—For a given groove there is always a given shape of car-wheel flange that is best suited to that groove, so that, when buying car wheels, care must be taken that the flanges are of suitable shape, otherwise there will be excessive wear in the groove and on the wheel flange. A wheel flange must be of a certain depth in order to keep the car on the track; if the depth of the groove and the depth of the flange of the wheel are about the same, the least bit of wear in the tread of the wheel will allow the weight of the car to rest on the flange, which is not designed to carry it. If the wheel flanges are deeper than the groove, the wheels cannot be used at all. A track of the ordinary grooved rail must be gauged with great exactness, because a variation in either direction will cause the wheels to bind. If the gauge is too narrow, the outsides of the wheel flanges bind against the sides of the rail treads; if the rails are too far apart, the insides of the wheel flanges bind against the side of the rail check.

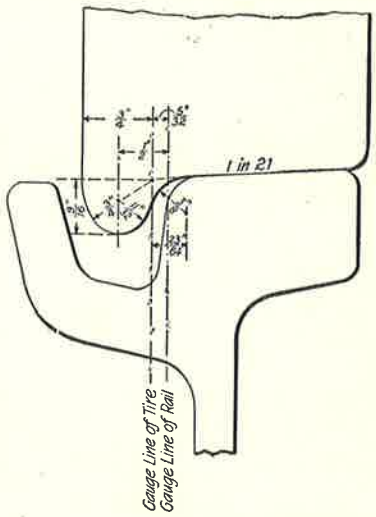


FIG. 5

GAUGE MEASUREMENT AND RAIL ADJUSTMENT

12. Gauge Measurements. — The gauge of the track is measured by a *track gauge*, as shown in Fig. 4 (*a*), and the distance between the car wheels is measured by a *wheel gauge*, as shown in Fig. 4 (*b*). Fig. 5 shows a section of a car tire in position on the rail, the vertical dotted lines showing the points to which the gauge measurements are taken. The gauge of the wheels is slightly less than the track gauge in order to prevent binding, the wheel gauges for a 4′ 8½″ track gauge being 4 feet $8\frac{3}{16}$ inches, and for a 3′ 6″ track 3 feet $5\frac{11}{16}$ inches. The width of tires recommended for the different rail sections is given in Table III.

TABLE III

WIDTH OF WHEEL TREAD FOR BRITISH STANDARD RAILS

British Standard Rail Section Number	Width of Tire Inches
1 and 1*c*	$2\frac{7}{8}$
2 and 2*c*	$2\frac{15}{16}$
3 and 3*c*	3
4 and 4*c*	$3\frac{1}{8}$
5 and 5*c*	$3\frac{1}{4}$

13. Tie-Bars.—In order to keep the rails true to gauge they are fastened together every 6 to 12 feet with **tie-bars** or **tie-rods,** which usually consist of bars of steel of rectangular section, terminating at one or both ends in a screwed rod carrying nuts and washers. Sometimes the tie-rods are circular throughout the whole of their length. The two most common types of tie-bars are shown in Fig. 6 (*a*) and (*b*). The variety shown in Fig. 6 (*a*) is known as the single-ended type, one end only being screwed, and the other end furnished with slots, as shown.

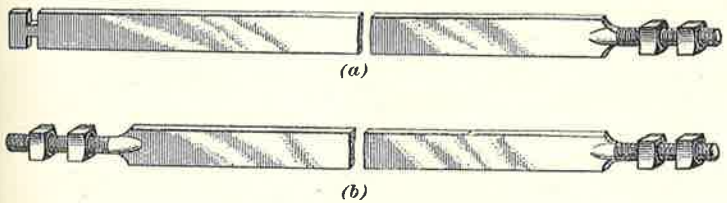


FIG. 6

Fig. 6 (*b*) shows the double-ended type, which is screwed at both ends. To enable the tie-bars to be attached to the rails, slots 2 to 3 inches long are punched in the webs of the rails at the desired intervals. If the single-ended tie-bar is used, the notched end is pushed sidewise through the slot, as shown in Fig. 7 (*a*), and is then turned round into the position shown in Fig. 7 (*b*), all adjustments being made from the other end by means of the nuts. The way in which the double-ended type is attached to the rail is shown in Fig. 7 (*c*); with this type of tie-bar, adjustment can be made from either end.

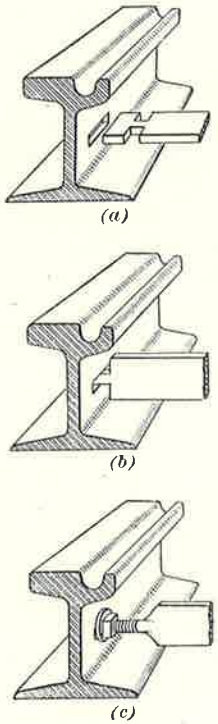


Fig. 7

14. The sizes and weights of standard steel tie-bars for broad- and narrow-gauge tracks are given in Table IV. The number of tons of tie-bars required per mile of single track is calculated on the assumption that the tie-bars are placed 7 feet 6 inches apart. For example, the number of tie-bars per mile of single track is $\frac{5{,}280}{7{\cdot}5} = 704$. For a track having a gauge of 4 feet $8\frac{1}{2}$ inches, the weight of one tie-bar $2\frac{1}{2}$ inches by $\frac{3}{8}$ inch is $16\frac{1}{2}$ pounds. The number of tons required per mile will therefore be $\frac{704 \times 16\frac{1}{2}}{2{,}240} = 5{\cdot}18$, as shown by the table.

TABLE IV

SIZES AND WEIGHTS OF STANDARD STEEL TIE-BARS

Gauge of Track		2 Inches by $\frac{1}{4}$ Inch		$2\frac{1}{2}$ Inches by $\frac{1}{4}$ Inch		2 Inches by $\frac{3}{8}$ Inch		$2\frac{1}{2}$ Inches by $\frac{3}{8}$ Inch	
Ft.	In.	Weight of Each Pounds	Tons Per Mile	Weight of Each Pounds	Tons Per Mile	Weight of Each Pounds	Tons Per Mile	Weight of Each Pounds	Tons Per Mile
3	6	$9\frac{1}{2}$	2·98	11	3·46	11	3·46	13	4·08
4	$8\frac{1}{2}$	12	3·77	14	4·4	14	4·4	$16\frac{1}{2}$	5·18

RAIL ANCHORS

15. Inverted-Rail Anchor.—In order to prevent any motion between the rails and the concrete foundation of the permanent way it has become customary, in recent constructions, to fasten the rails to the concrete at intervals by means of projections called **rail anchors**, which are bolted to the rail flange and embedded in the concrete. A simple and effective method of doing this is to bolt or rivet a short length of old rail to the under side of the track rail, flange to flange, as shown in Fig. 8, where *a* is the track rail, and *b* the old rail section riveted to *a* and embedded in the concrete *c*. The granite setts are shown at *d*, and the space *e* between the rail and the setts is filled in with cement. When these anchors are used at joints between the rails, they are 24 inches long; but when used at intermediate positions, the length is 18 inches. Anchors of this kind are used about every 20 feet.

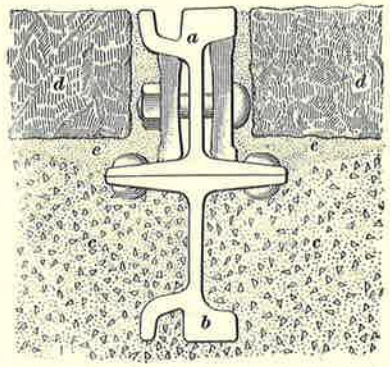


Fig. 8

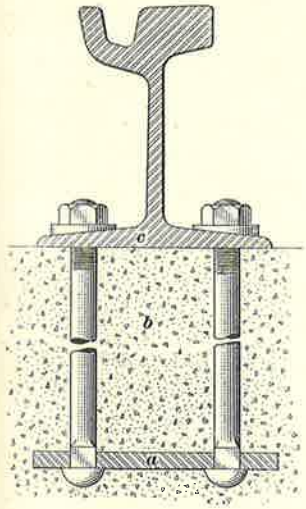


Fig. 9

16. Other Types of Anchors. Another simple type of rail anchor is shown in Fig. 9. It consists of a steel plate *a* embedded in the concrete *b* and bolted to the rail flange *c* by means of two 8-inch bolts. A type of rail anchor which gives an exceedingly rigid track consists of lengths of channel iron or old rail placed across the track and bolted to the rails to form sleepers, as shown in Fig. 10,

where the track rails are lettered *a* and the transverse sleeper

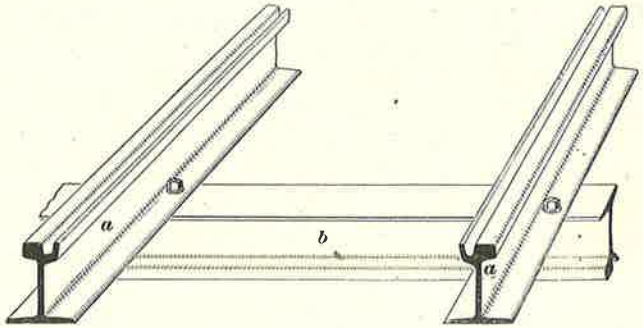


FIG. 10

of old rail *b*. This sleeper is embedded in the concrete on which the track rails stand, as in the previous cases.

DRAIN RAILS

17. Serious trouble is often caused in wet weather by the large amount of water which flows along the grooves of the rails. The water sometimes finds its way between the rail joints, and flows down to the concrete bed on which the rails rest; if this water freezes, it damages the track by lifting and loosening the paving and joints. In order to get rid of the water, **drain rails,** which carry the water to the sewers, are inserted in the track at intervals. Fig. 11 shows a section of a drain rail. The tread of the rail is at *a*, and a slot about 12 inches long is cast in the bottom of the groove, as at *b*, to allow the water flowing along the rail to fall into the box *c*, and thence to the sewer by the pipe *d*. The box *c* is provided with a removable lid *e*, so that the pipe *d* can be kept clear of mud. Under ordinary conditions,

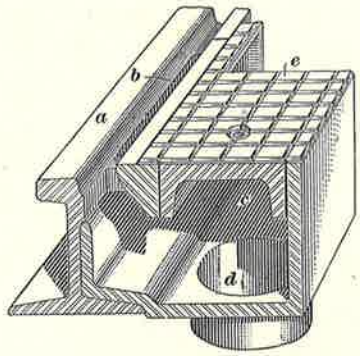


FIG. 11

however, the device is practically self-cleaning, and requires very little attention. The drain rail is usually from 6 feet to 8 feet 6 inches long, and is attached to the regular track rails in the usual way by means of *fish-plates*.

RAIL JOINTS

MECHANICAL JOINTS

18. Fish-Plate Joint.—No part of the permanent way requires greater care than the rail joints; in fact, the life of the rail is often limited by the life at the joint. If there is any looseness or unevenness, the pounding of the car wheels soon flattens the rail at the ends, and once the flattening has started the rate of deterioration increases greatly.

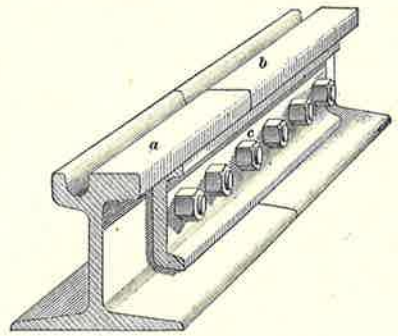


FIG. 12

The usual method of jointing the rails is to bolt them together by means of channel-shaped strips of steel, called **fish-plates,** as shown in Fig. 12, where *a* and *b* are the two rails to be jointed, and *c* is one of the fish-plates. One fish-plate is used on each side of the web, as shown in Fig. 13, which gives a sectional view of the fish-plates and rails. The fish-plates are secured to the rail by six bolts, three in each rail; they are spaced 4 inches apart, the first bolt being 2 inches from the end of the rail. Where the rails

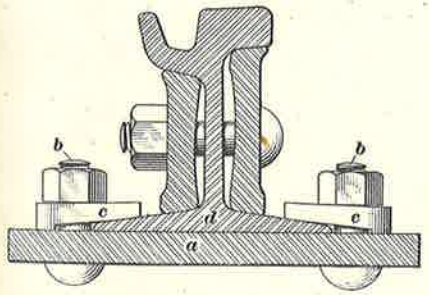


FIG. 13

are $6\frac{1}{2}$ inches deep the centre line of the bolts is $2\frac{3}{4}$ inches from the under side of the flange, and for 7-inch rails the distance is 3 inches. Fish-plates for standard rails are 24 inches long, and the weights for the various sizes of rails are given in Table V.

TABLE V

WEIGHTS OF FISH-PLATES FOR STANDARD RAILS

British Standard Rail Section Number	Weight of Inner Fish-Plate Pounds	Weight of Outer Fish-Plate Pounds
1 and 1*c*	$22\frac{1}{2}$	$27\frac{1}{2}$
2 and 2*c*	$22\frac{1}{2}$	27
3 and 3*c*	$22\frac{1}{2}$	$26\frac{1}{2}$
4 and 4*c*	26	$30\frac{1}{2}$
5 and 5*c*	26	$30\frac{1}{2}$

19. Sole-Plate Joint. In order further to strengthen the joint, flat plates of steel, called **sole plates,** are often attached to the bottom of the flange of the track rail, as shown in Fig. 13, where *a* is the sole plate, fixed by means of the bolts *b* and clips *c* to the flange *d*. Compared with the fish-plates, the sole plate, which is usually made about 1 inch thick, offers but little resistance to bending, and is often replaced by a short length of steel joist or old rail bolted flange to flange with the running rail, as described in connection with rail anchors.

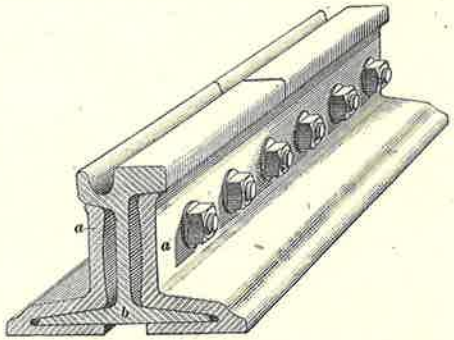


FIG. 14

20. Continuous Joint.—A type of joint known as the **continuous joint** is illustrated in Fig. 14. It consists of a combination of fish- and sole plates, the fish-plates *a* being extended and taken under the flange *b* of the track rail, making the joint rigid, and keeping the rails alined.

21. Rail Expansion.—Rails are subjected to considerable variations in temperature, which cause corresponding changes

in their lengths. On ordinary steam- or electric-railway lines, where there is no paving, expansion is allowed for by making the bolt holes in the rails in the form of slots, so that the rails can move slightly in a horizontal direction between the fish-plates. Thus, in cold weather there will be a gap of perhaps $\frac{1}{4}$ to $\frac{5}{16}$ inch between the rail ends, while in warm weather there will be scarcely any space at all. Mild steel expands ·0000117 of its length for each degree centigrade increase in temperature. Assuming that the extreme difference in temperature to which the rail is subjected is 55·5° C., a track would be ·0000117 × 55·5 = ·00065, approximately, of its length longer in the hottest weather than in the coldest.

A stress of 1,000 pounds per square inch will stretch a mild-steel bar ·00003 of its length. Hence, if a rail is stretched ·00065 of its length, the stress per square inch of cross-section of the rail will be $\frac{\cdot 00065}{\cdot 00003} \times 1{,}000 = 21{,}666$ pounds. If the rails are continuous and firmly anchored, so that there is no play at the joints, the track as a whole cannot expand and contract, so that the force of expansion must be taken up by putting stress on the rails. The rails will tend to expand with increase in temperature, thus causing compressive stresses; and on tending to contract with decrease in temperature, the rails will be stretched, but the stresses so caused will not exceed 22,000 pounds per square inch under the conditions assumed. A safe value for the elastic limit of steel is 40,000 pounds per square inch; that is, steel subjected to any stress below this amount will not take a permanent set, but will return to its original length when the stress is removed.

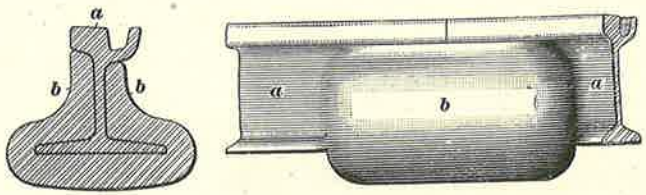
22. For the foregoing reasons, if a track is constructed so that it cannot buckle sidewise and get out of line, there is no objection to butting the ends of the rails together and fastening them by means of some form of joint that allows no longitudinal motion whatever. In paved streets this condition is met, and it is now common practice to use methods of rail joining that give a continuous rail. Jointless rails reduce wear on both rolling stock and track by giving a smooth running surface.

When the rails are embedded in paving, the surface exposed to the atmosphere is small and the rails are therefore not subjected to such rapid or extreme variations of temperature as on open tracks. There are a number of types of solid joint, the most important being the *cast-welded*, the *electrically welded*, and the *thermit*, of which the last is the most commonly used.

CAST-WELDED JOINT

23. Falk Joint.—A rail joint made by pouring molten cast iron into a mould which surrounds the abutting ends of the rails is generally known as the **Falk cast-welded joint.** The ends of the rails are first thoroughly cleaned for a distance of 6 or 8 inches on each side of the joint by means of a sand blast. A cast-iron mould is then clamped round the rail ends and molten iron poured in, thus forming a joint. In order to make these joints, a considerable amount of apparatus is required, a portable cupola for melting the iron and a sand blast for cleaning the rails being essential. To make the joints at all reasonable in cost, a large number must be made at a time. The weight of iron varies from 70 to 140 pounds, depending on the shape of the joint and the section of the rail.

24. It is usual practice to shape the mould so that the iron cast round the rail joint will have no sharp corners or edges. Fig. 15 (*a*) and (*b*) shows the section and side view of a common



(*a*) (*b*)

FIG. 15

form of Falk joint, the rail being lettered *a* and the cast iron *b*. In cast welding, the iron used is of a special chemical composition, and is poured at a much higher temperature than that used when making ordinary castings. The effect of this is that the cast

iron fuses into the surface of the steel rail, thus forming a joint that is strong mechanically and of high conductivity. It is claimed by some that cast welding anneals the ends of the rail, thus softening them and causing them to pound or flatten out more than the rest of the rail; but on a number of tracks where the cast-welded joint has been in use for several years, no bad effects from this cause have been noticed.

ELECTRICALLY WELDED JOINT

25. Equipment for Electric Welding.—The method of making electrically welded joints, as introduced by the Lorain Steel Company, consists in welding bars to each side of the web of the rail by passing a very large electric current through the bars and rail. Quite an elaborate outfit is required for this process, which, like cast welding, is only applicable where a large number of joints are to be made. The outfit consists of four cars: first, a sand-blast car; second, the car carrying the welder; third, a car attached to the welding car and carrying the rotary converter and transforming apparatus for supplying the welder with alternating current; fourth, a car provided with machinery for grinding off the rail treads after the joints have been welded. The cars are arranged in the order named. The first car contains a sand-blast tank and a motor-driven air compressor for operating the blast by means of which the web of the rail and the surfaces of the plates are thoroughly cleaned before the welding operation takes place.

26. Splice Bars. To make the joint, a mild-steel plate, similar to that shown in Fig. 16, is welded on each side of the web; the finished joint appears as shown in Fig. 17. Each bar is welded in three places corresponding to the raised parts *a*, *b*, *c*, Fig. 16. The bosses *a*, *b*

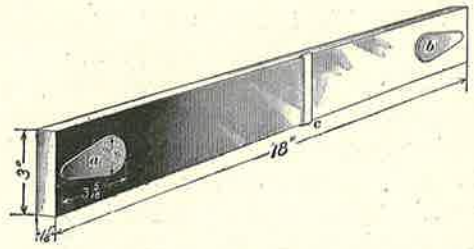


FIG. 16

at the ends of the bar are formed under a drop hammer, which forces the metal in on one side and out on the other, the depression on one side being afterwards filled with a piece of metal

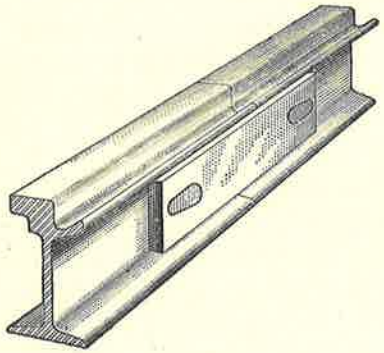


Fig. 17

The boss at *c*, which comes opposite the joint between the rails, is made by welding a small strip of steel over the bar. The object of the bosses is to localize the welding current and thus confine the welding to a certain area; each boss has an area of about $3\frac{1}{2}$ square inches, so that the welded area on each bar is about $10\frac{1}{2}$ square inches, or 21 square inches for the two bars. After the rails have been cleaned, lined up carefully, and the bars wedged in position, the joint is ready for welding by means of the electric welder suspended from the front of the second car.

27. Action of Welder. — The main parts of the welder and their relation to the joint are shown in Fig. 18. The two splice bars *a*, *a* are located so that the centre boss comes opposite the end of rail *b*. The terminals *c*, *d* of the welding transformer *e* are pressed against the splice bars by means of levers *f*, *g* that are pushed apart at their upper ends by pistons working in a hydraulic cylinder *h*. Just sufficient pressure is applied to hold the bars in place and provide good contact. The secondary of the transformer consists of a single loop of very heavy conductor, so that a very large current at low pressure is delivered. The whole welding apparatus is

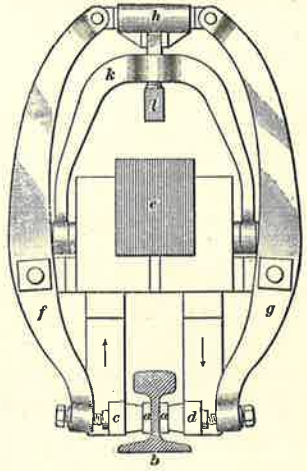


Fig. 18

suspended from a yoke *k* carried by an arm *l* extending from the front of the car and arranged so that the welder can be moved in any direction to permit an easy and rapid adjustment to the joint. The primary of the transformer is supplied with alternating current obtained from a rotary converter placed in the third car and driven by direct current from the trolley wire. Suitable regulating devices are provided so that the voltage applied to the welder can be maintained fairly constant, even though the trolley voltage varies considerably.

28. Method of Making Joint.—The weld in the centres of the bars is made first. In about $2\frac{1}{2}$ minutes after the current is turned on, the joint is brought up to a welding heat; the current is then cut off and the pressure on the joint increased by the hydraulic cylinder *h*, the maximum pressure applied being about 35 tons. After a few moments, the pressure is released and the welder adjusted to one of the end welds, where the process is

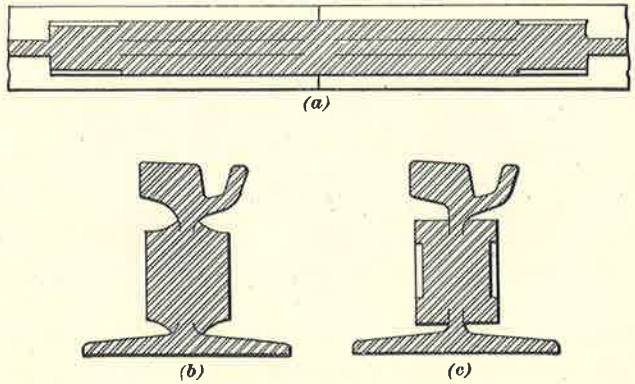


Fig. 19

repeated, only, with both end welds, the heavy pressure is maintained until the metal has cooled below a glowing heat; it has been found that this makes the weld tougher. Since the middle weld is made first, the bars become expanded because of the heat, and since the end welds are made before the middle weld has cooled off, the ends of the bars are fastened to the rail while the metal is expanded. Hence, as the bars cool, the ends of the rail are pulled together, thus making a very close joint

between the rail ends. Fig. 19 (*a*) shows a horizontal section of a completed joint ; (*b*) and (*c*) show vertical sections, (*b*) being a section of the centre weld and (*c*) of an end weld.

29. The secondary of the welding transformer develops a pressure of about 7 volts, and the current used for a weld is about 25,000 amperes. The secondary voltage, however, drops somewhat when this large current is flowing, so that the power actually taken from the line is not as great as $25{,}000 \times 7 = 175$ kilowatts. As a general rule, about 125 kilowatts for $2\frac{1}{2}$ minutes is sufficient for welding an ordinary joint. On the average, about 80 joints can be made in 24 hours ; as a continuous process, working day and night, it takes from 13 to 15 minutes per joint.

The electrically welded joint is very strong, and, when tested, rails seldom pull apart at the point of welding. Also, the head of the rail is not made hot enough to soften it, and the splice bars do not occupy much room.

THERMIT-WELDED JOINT

30. Action of Thermit in Producing Heat.—A method of making solid rail joints which is now much used is the **thermit process,** invented by Dr. Hans Goldschmidt. It has shown remarkably good results and gives a joint equal to the rail in conductivity. Careful measurements have shown that the wear at the joints after a year's service does not exceed, appreciably, the wear on the rail.

Thermit is a mixture of finely divided iron oxide and aluminium. The metal aluminium has a great affinity for oxygen, and if this mixture is given a local initial heating by so-called *ignition powder*, a very rapid chemical reaction takes place throughout the whole mixture, and a large amount of heat is liberated. The iron oxide gives up its oxygen to the aluminium, and aluminium oxide is formed ; at the same time the iron oxide is reduced to pure iron. The heat produced by the reaction is so intense that the mass of molten iron has a temperature of about 3,000° C., and if poured round a properly prepared rail joint a perfect weld will result.

31. Equipment for Thermit Welding.—The appliances required for making a joint by this process are very simple and easily moved from place to place ; the cost per joint is practically the same whether a few or many are made, and in this respect the process possesses an advantage over cast welding and electric welding, which are practically out of the question if only a few joints are to be made. Fig. 20 shows a rail joint made with thermit, and Fig. 21 shows the moulds that are clamped on either side of the rail to receive the melted metal. These vary in form according to the shape of the rail section, and are made by placing a sheet-iron case (*b*) over a model, or pattern, of the joint and tamping it full of a good quality of sand. The moulds for the two sides of a rail are shown in (*a*) and (*c*). The edges of the mould are smeared with clay, so

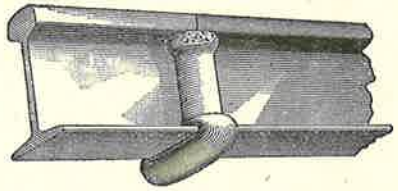
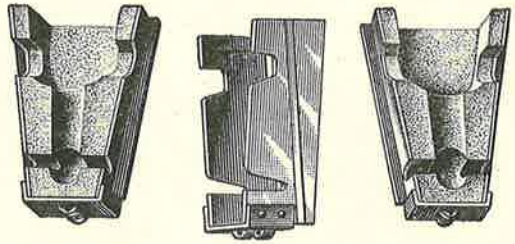


FIG. 20



(*a*) (*b*) (*c*)

FIG. 21

as to form a tight joint, and the halves are then clamped into position on the rails. The thermit compound is placed in a cone-shaped crucible mounted on a projection from the rail clamps directly over the mould ; about 20 pounds of thermit is used for each joint, the exact amount required depending on the size of the rail. The crucible is composed of an iron case lined with magnesia, and the bottom is formed of a hard magnesia stone provided with a renewable outlet that will stand about five runs. The hole in the outlet is stopped by a plug.

32. Method of Making the Joint.—The ends of the rails to be welded are first well cleaned with a fine flat file and emery cloth. The rails are then fixed firmly end to end by means of powerful clamps, care being taken to get them exactly level and in line. The joint is next thoroughly heated up, by means of blow lamps, to ensure that there is no moisture present. When the rails are so hot that they can hardly be touched by the hand, they are brushed vigorously with a hard steel-wire scratch brush, and the moulds are adjusted and fixed in position on the rails. The rail

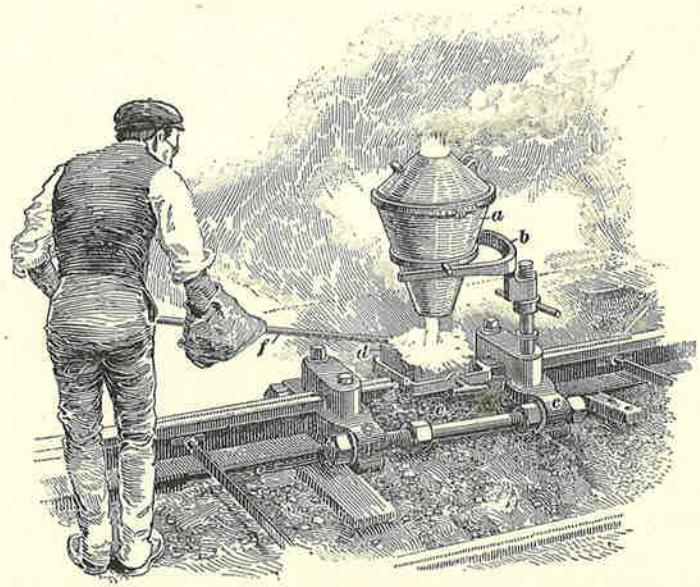


FIG. 22

head and groove should be protected from contact with the molten steel by a thin coating of clay. Both the sand surfaces of the mould, and the clay used for protecting the rail, should be thoroughly dried off by means of a blow lamp before the weld is made. If any moisture is present either on the rail ends or in the mould or clay, steam will be given off when the weld is made, and the metal will be rendered porous. All joints between the mould and the rail are filled with clay, and sand and earth are packed round the mould.

33. When the mould is in place, the crucible is fixed in the holder, with its outlet exactly above the runner of the mould and 6 or 7 inches from it. A small amount of ignition powder is then placed on top of the thermit and lighted by means of a match ; in a few seconds the chemical reaction is over and the lower part of the crucible contains a mass of liquid steel at very high temperature, while the slag, consisting of aluminium oxide or corundum, floats on top. The crucible is then tapped by knocking the plug in the bottom upwards with a flat-ended iron rod, and the steel runs into the mould in a $\frac{1}{2}$-inch stream. The weight of steel obtained from the reaction is one-half the weight of the

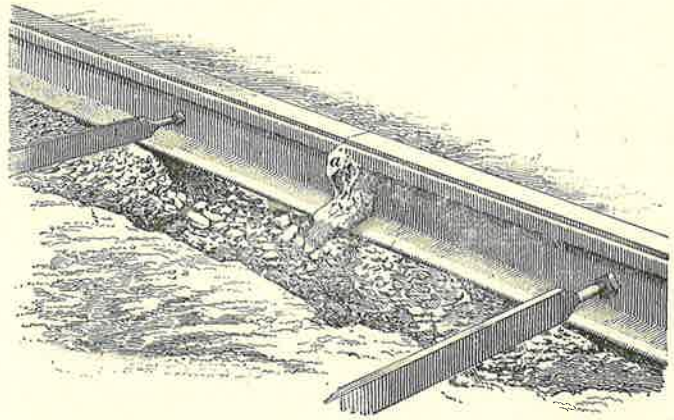


FIG. 23

thermit mixture. The mould is made so that the metal strikes the under part of the rail first and works its way up to the top, thus carrying up any dirt or slag that may be present. The steel is so extremely hot that it alloys instantly with the ends of the rail, and as substances such as manganese or silicon are generally incorporated in the thermit mixture, the steel has approximately the same composition as the rail. After the metal becomes solid, the moulds may be removed. Any surplus metal should be hammered, while still hot, under the head and check of the rail.

34. Fig. 22 shows the operation of making a weld. The crucible *a* is supported in the holder *b*, which is attached to the powerful clamp *c* used for forcing together the rail ends. The

mould is clearly seen at *d*, the lower part of it being surrounded by sand and earth as shown at *e*. The bar with which the crucible is tapped is shown at *f*. It is advisable for the men employed in making the welds to wear spectacles with dark glasses, as the glare from the molten steel is very vivid, and is likely to injure the eyes. Fig. 23 shows a completed joint, immediately after the removal of the moulds, before the metal has been hammered. It will be seen that the space occupied by the band of steel *a* round the weld is very small.

RAIL CORRUGATION

FORMATION OF CORRUGATIONS

35. Probable Cause.—One serious permanent-way trouble which has followed the introduction of electric traction is what is called **rail corrugation,** which is the formation on the tread of the rail of small waves commonly from $1\frac{1}{2}$ to 4 inches between the crests, which are at right angles to the rail length. These corrugations may be up to 30 inches long.

Many theories have been put forward as to the cause of corrugation, the most common laying the blame on the method of rail manufacture, on the method of laying the track, or on the rolling stock running over the lines. As regards the rail manufacture, it has been pointed out that the cause might be due to the use of obsolete machinery for rolling the rails, the worn gear-wheels of which caused a chattering action to take place, which produced the wavy effect on the rail tread. The absence of corrugation on steam railways in Great Britain has led others to think that the cause of the trouble was the rigid construction of the track, and a resilient track was suggested. A third theory assigns the blame to the rolling stock, suggesting that the trouble is due to defective trucks, in which the axles are not at right angles to the track. It is also suggested that this causes unequal wear on the wheels, and, as the wheels are fixed rigidly to the axle, one of them must skid slightly to revolve at the same rate as the other, thus grinding the rail into waves.

36. In order to test whether or not the trouble was due to the rails, experiments have been made by interchanging a smooth rail and a corrugated one. The result was that the corrugated rail became smooth and the smooth one corrugated. This test practically cleared the rails of any responsibility in the matter.

The question of making the track flexible is one which is decided at once by the paving. If the track were flexible, the paving could not be kept in order, as the paving blocks of wood or other material would be worked out of position and would be a continual source of trouble. In addition to this, the forces due to rail expansion necessitate a rigid track.

The whole question is being carefully studied, and at present conclusions seem to point to intermittent skidding of one wheel with respect to the other as the cause of the trouble. This skidding may be produced by unequal wheel diameters, due either to wear or to the use of coned wheel flanges, the intermittent effect of the skidding being increased by dust on the track rails.

REMOVAL OF CORRUGATIONS

37. Methods of Grinding.—Once corrugations have formed on a rail, the running of the cars becomes very unsatisfactory, the trucks being badly shaken, and the noise made by the cars such as to give rise to complaints from residents in the neighbourhood. The only way to deal with a corrugated rail is to grind the waves off its surface, and several forms of grinders are in use for this purpose. The first and simplest is formed by attaching a block of carborundum in a suitable manner to the frame of a car. The car is then run backwards and forwards over the rail with the block screwed

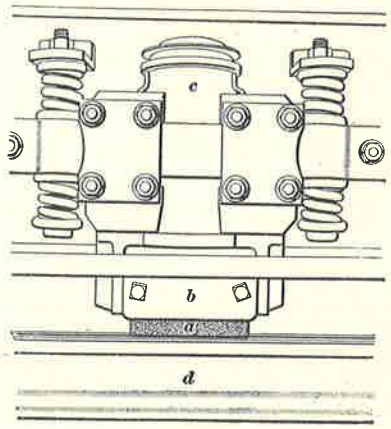


FIG. 24

hard down, and the corrugations are gradually reduced till the rail is perfectly smooth. In order to control the raising and lowering of the block, it is sometimes fitted to an electromagnet, the current from the trolley wire being switched on from the driver's platform, and the block let down where required. Fig. 24 shows an electromagnetic grinder attached to the car truck. The carborundum block *a* is clamped in the holder *b* and controlled by the electromagnet *c*. The block is shown in the operating position pressing on the rail *d*.

38. The second method in use is to have a special truck constructed and fitted with a motor driving carborundum wheels close to the rail tread, arrangements being made for lowering the grinding wheels as required. The truck is driven slowly over the route and the carborundum wheels are driven at a high rate of speed and adjusted to take the necessary amount off the tread. As the rails are corrugated, if the wheels of the grinding truck rested on them the unevenness would be reproduced at the grinding wheels, so the wheels are turned with specially deep flanges and run on the bottom of the groove of the rail, which is thoroughly cleaned out before the grinding commences. This type of grinder operates rather slowly for the removal of corrugations, but is very suitable for smoothing the rails where they are pounded at joints.

SPECIAL TRACK WORK

LAYOUT AND TYPES OF SPECIAL WORK

39. Layout of Special Work.—All roads have a number of crossings, curves, branch-offs, cross-overs, etc., and since these are different from straight track, in that they involve special care and precautions in their installation, they are all included under the general name of **special work.** Important special work is completed at the steelworks and sent ready to install.

As the construction of special work must be carried out with great accuracy, it is generally done step by step, and each stage of the work is carefully checked. The site of the special work

is first measured up and surveyed carefully, and a drawing is made of the proposed arrangement. This drawing is carefully checked, and is used as a means of laying out the work full size, with chalk, on a large smooth wooden floor. If the proposed method of construction is found to be satisfactory, the floor lines and angles are taken as guides for making wooden templates to be used by the patternmaker and the rail bender. When the separate parts of the job are complete, it is set up in the laying-out yard, where any slight errors are detected and rectified.

40. Types of Special Work.—A **plain curve,** in the sense that it is not complicated by any branch-offs, turnouts, or other special features, is shown in Fig. 25 (*a*). Such a curve can be simple or compound, single or double, right-hand or left-hand. A **left-hand branch** is shown at (*b*) and a **right-hand branch** at (*c*); these are used where a branch road leaves the main line. Facing the point of departure of the branch from the main line a right-hand branch turns to the right and a left-hand branch to the left. A **connecting curve and crossing** are shown at (*d*); the connecting curve in this case is a right-hand branch from the horizontal straight track and a left-hand branch from the vertical one. The diagram (*e*) shows a **plain Y**, (*f*) shows a **three-part Y**, and (*g*) a **through Y**; the three-part **Y** can be used instead of a loop to turn single-end cars at the end of the line. At (*h*) is shown a **reverse** or **S curve,** such as is often used where a cross-street is broken at the main street. At (*k*) is shown a **right-hand** and at (*l*) a **left-hand cross-over,** used to cross over from one track to the other; these are very convenient devices to place at intervals in a main line to turn cars back when they are disabled or when it is desirable to do so for other reasons. When it is practicable, a cross-over should be put in so that its switch points will lie in the direction of travel on the two tracks. A **diamond** or **Y turnout** is shown at (*m*), at (*n*) is an ordinary **siding,** or **side turnout,** and at (*o*) a **right-hand thrown-over turnout,** seen very often in temporary work, where it is of the nature of a temporary cross-over to avoid a gang of workmen. An interlacing line is shown at (*p*); this is used where a double-track construction comes to a narrow portion of the road.

If a single track were put in, spring points would be required,

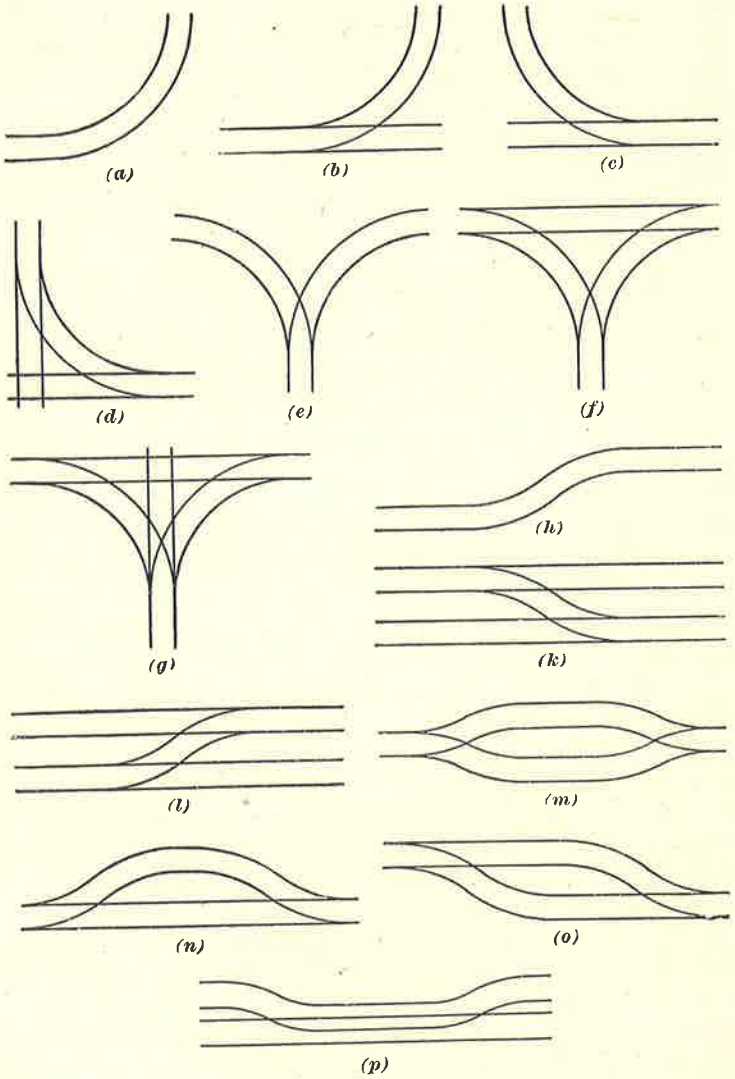


FIG. 25

and the wear on the single-track rails would be twice that on the adjacent double-track rails.

CURVES

41. Kinds of Curves.—Curves are of two kinds, *simple* and *compound*, or *transition*, curves. A **simple curve** is one that is described with only one radius throughout its length, while a **compound curve** is one so constructed that the radii become shorter as the middle point of the curve is approached from either end. A compound curve gives easier riding than a simple curve, because the direction in which the car is moving is changed more gradually. Tramway-track curves are always designated by the radius, in feet, at the centre. The rails are bent to the desired radius by means of a *rail bender* or *crow*, one type of which is shown in Fig. 26. The rail is supported by the arms *a* and *b*, and pressure is applied to the block *c* by means of the screw *d*, which is turned by means of a crow-bar inserted in the holes *e*. Both the arms and the block are shaped to take the full section of the rail, so that pressure is applied evenly to all parts of it, and twisting of the rail or crushing of the groove is avoided. For bending heavy rails, or in cases where there is a large amount of rail bending to be done, presses actuated by hydraulic pressure are employed.

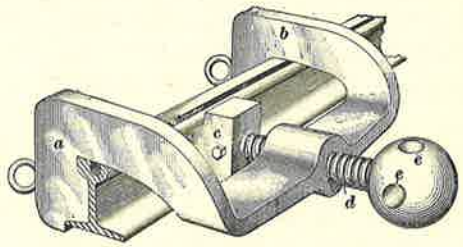


FIG. 26

42. Considerations for Laying Out Curves.—A very important point about laying out a single-track curve is to be certain that a car will go round it freely without either end striking any obstruction, and in the case of double track that the cars will clear one another. Whether or not two cars can pass each other on any given curve depends on the following: The length and width of the car; the amount by which the ends overhang the wheel base; the length of the wheel base; on double-truck cars, the distance between trucks; the distance

between the track centres; the amount of curvature of the track; and the elevation of the outside rail. A good method is to lay out to scale on paper a plan of the proposed curve; then, by means of a pasteboard dummy that scales the dimensions of the outside lines of the car, the actual clearance at all points can be readily determined. The positions of the car wheels may be indicated by holes through which the track can be seen, or transparent paper may be used, so that the dummy can be made to take the right path round the curve. Another point to be looked after in cutting out a dummy is to see that the widest part of the car is represented. To ensure some degree of safety to the heads and arms of passengers, the clearance on both sides of the car should be at least 15 inches, if cars are to pass each other on curves. Special attention must be paid to this feature where the centre-pole method of overhead construction is used.

43. Transition, or Compound, Curves.—By combining curves of different radii, a compound or transition curve is formed, such that the entrance of the car into the curve is gradual, and a sudden shock is avoided. The curve at the point where it branches from the straight part of the track, or a tangent, as it is called, is of long radius and the radii are gradually decreased until the radius of the centre of the curve is reached. Theoretically, the correct method would be to make a true spiral connection between the tangent and the centre of the curve, but this would be impracticable. Steel companies making a speciality of trackwork for electric tramways have developed standard transition curves that approximate to a spiral sufficiently closely for all practical purposes. For example, the Lorain standard curve for a radius at the centre of the curve varying from 40 feet to 62 feet 6 inches has an entrance radius of 432 feet.

At one time, curves for electric tramways were made up of arcs of different radii struck from three or five different centres, thus giving a rough approximation to a spiral. Curves as now used are made up of a number of radii such that the length of arc of any one radius is not over 5 feet. This gives a curve that is practically as smooth riding as a true spiral.

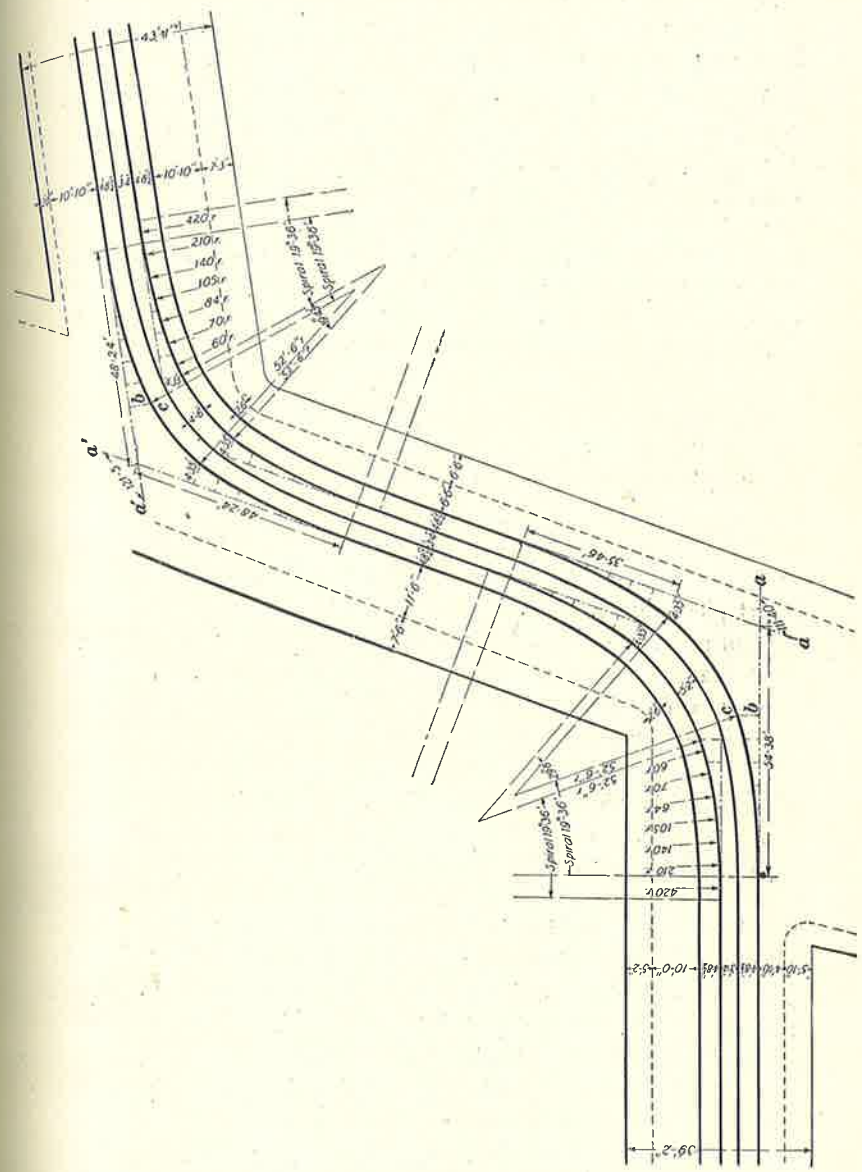


FIG. 27

44. The principal dimensions of a compound reverse curve for a special case are given in Fig. 27. The angles between the straight tracks, or tangents to the curves are shown at *a* and *a'*, and a number of radii of the lengths indicated are used to construct arcs of about 5 feet in length which make up the curve. The position of the rail is checked by measuring the distance from the end of each arc to the tangent line, as shown by *b c*. The plan of the curve shows that the distance between the tracks is increased from 3 feet 4 inches to 4 feet 6 inches in one case and to 5 feet 2 inches in the other in order that the cars may pass on the curves. The minimum distance between the inner part of each curve and the kerb is 2 feet 6 inches.

45. Construction of Special Work.—In special track work, the greatest wear takes place at the points, which are subjected to the pounding action of the wheels caused by the breaks in the tread of the rail. On this account, points and crossings are now supplied either cast altogether in manganese steel or made of toughened cast steel and fitted with manganese-steel insert pieces at the wearing points. Fig. 28 (*a*) shows the latter type of point, the insert pieces being enclosed by the heavy lines. Each track is provided with two points, one of which is usually without a movable tongue, and is called a *fixed point*; the other is furnished with a tongue which is free to move, and is known as a *movable point*. Fig. 28 (*b*) shows the fixed point and Fig. 28 (*a*) the movable point, which turns about the part *h*.

The sections *a a*, *b b*, *c c*, *d d*, and *e e* are those of the movable point, looking in the direction of arrow *A*. Section *f f* shows the construction of the end *h* of the point. Section *g g* is that of the fixed point, looking in the direction of arrow *B*. In some systems movable points are used on both rails. If the movable point is fitted with a spring to keep it closed always in one direction, it is called a *spring point*. This spring device is shown at section *e e* in Fig. 28 (*a*). Such points are usually fitted at turnouts, so that cars passing in one direction are made to pass into the turnout, while cars passing in the other direction are made to keep to the main line. In passing the trailing points the wheel flanges force over the movable tongue.

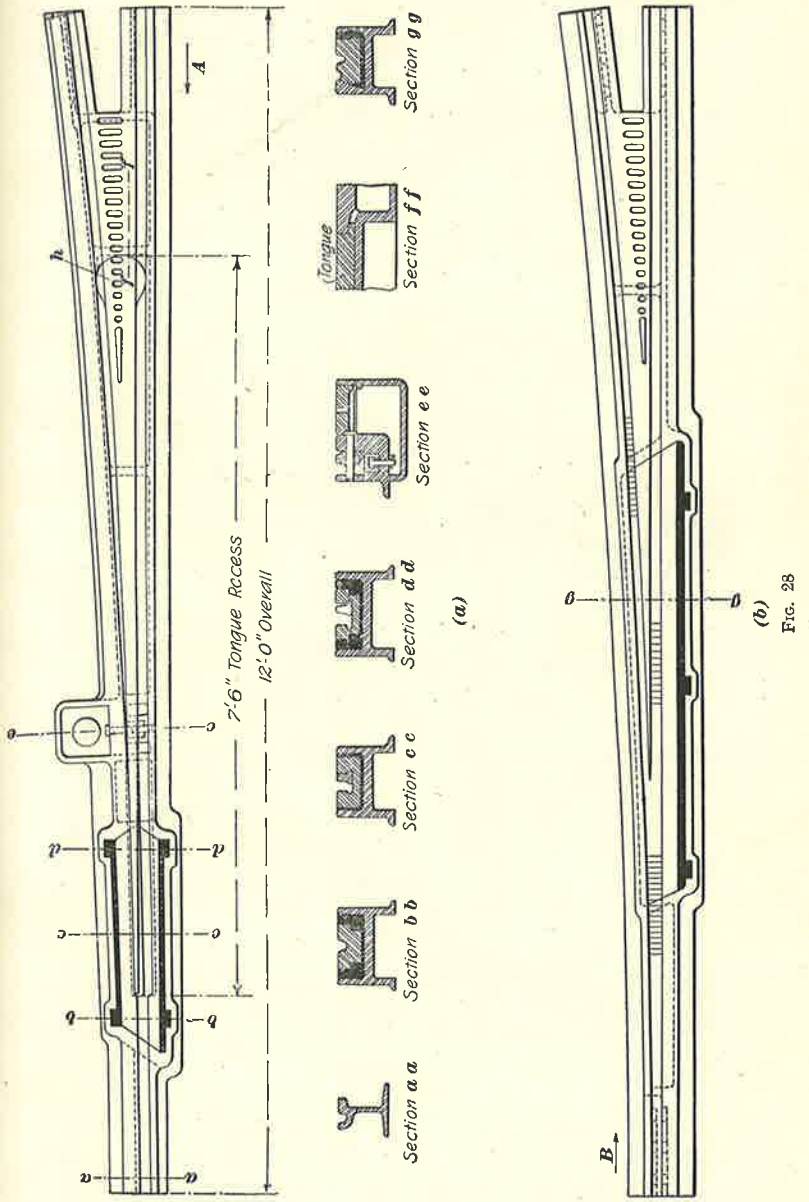


FIG. 28

46. A Hadfield manganese-steel point with a movable tongue *a* is shown in Fig. 29. The device for moving the tongue

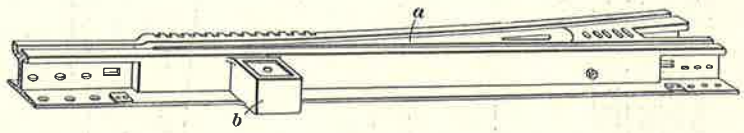


FIG. 29

is contained in the box *b*, and may consist of a spring or a bell-crank connection. These points are now usually supplied in

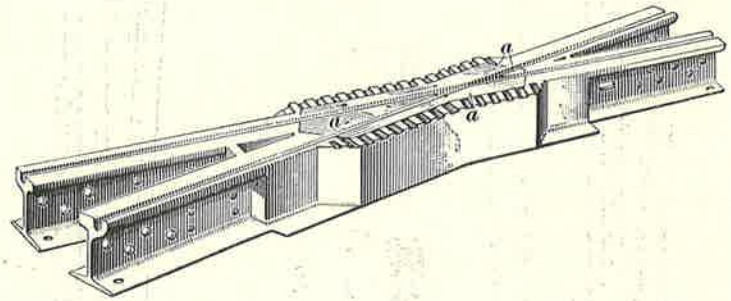


FIG. 30

lengths of from 9 to 12 feet; they should be well drained by connecting them to the sewer or surface-water drain by means of 5-inch drain pipes. From the illustration it will be seen that

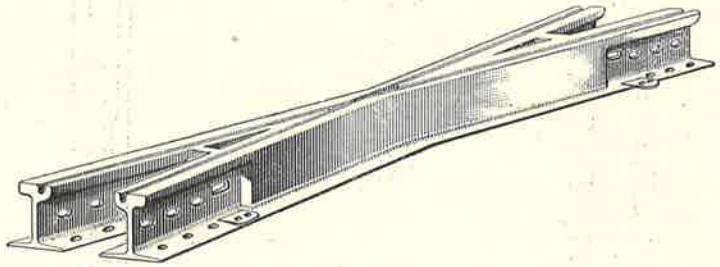


FIG. 31

the casting is finished off with a section the same as the section of the rail, so that the attachment to the rail can be made by means of fish-plates, as in an ordinary joint.

47. A cast-steel crossing provided with manganese-steel inserts *a* is shown in Fig. 30. The crossing shown in Fig. 31 is made of one piece of cast manganese steel.

The manganese steel used for these points and crossings is so hard that it cannot be drilled, though, if necessary, holes can be burnt by means of an electric arc. In general, however, the holes are cored in the rails when they are cast. Crossings are usually about 8 feet 6 inches long, and the angle is measured by the slope at the crossing. The usual angles are those corresponding to slopes of from 1 in 5 to 1 in 8.

48. The usual plan for a single-line turnout is shown in Fig. 32, and the arrangement of a standard cross-over for use

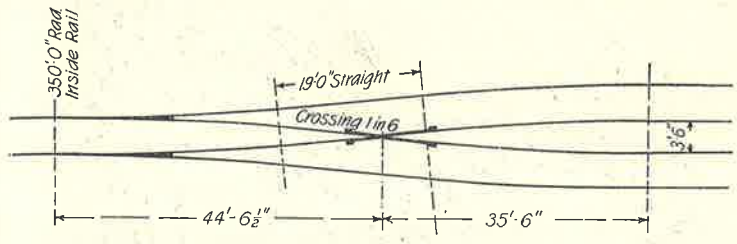


FIG. 32

with a double line in Fig. 33. The crossings that are required for use with the conduit system are very much more complicated and costly to make than those for the ordinary track, as the

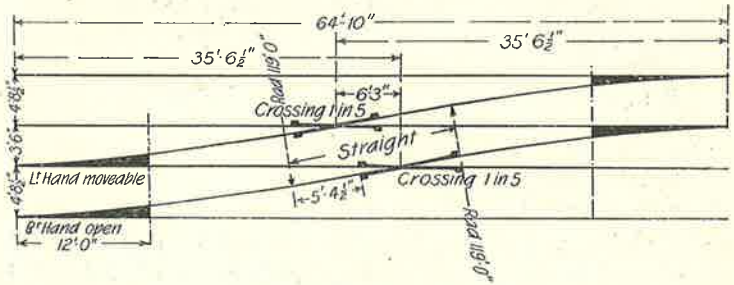


FIG. 33

central slot has to be held in place and the whole set supported over the duct. Fig. 34 shows a set of points and crossings for

a slot system, made by Hadfield's Steel Foundry Company, in course of erection at the maker's works.

The movable point *a* is sometimes known as a *tongue switch*, and the fixed point *b* as its *mate*. The use of the term switch in this connection is not to be recommended, however, as confusion is likely to ensue owing to the electrical use of the term.

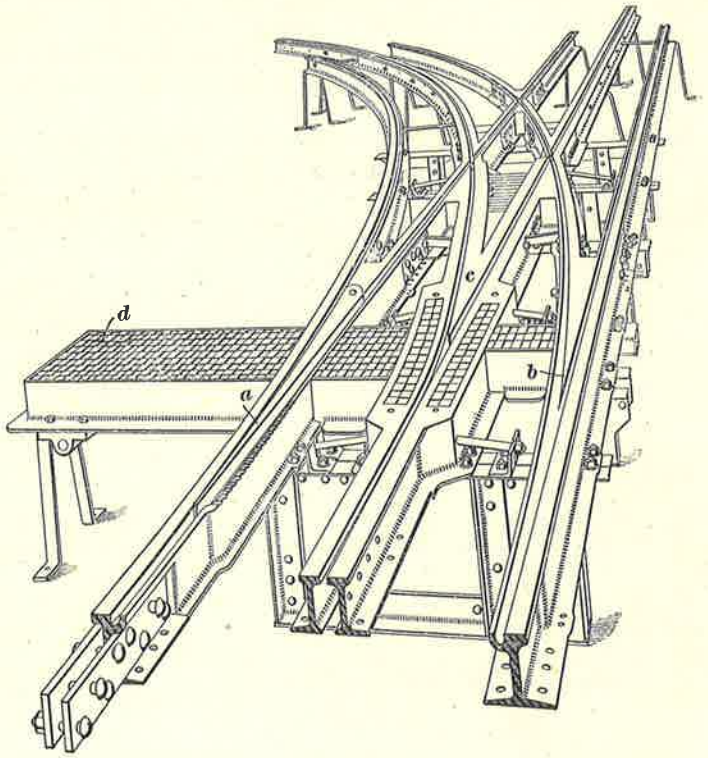


FIG. 34

The point for the conduit slot is shown at *c*, and both *a* and *c* are operated by means of a lever inserted in the slot *d*. If the special work is large, it is erected complete in a yard at the works instead of in the shops. By this method any inaccuracies in any part of the special work are discovered and can be remedied before the work is sent to the place where it is to be installed.

TRACK CONSTRUCTION AND PAVING

APPLICATION FOR PERMISSION TO CONSTRUCT TRAMWAYS

49. Procedure Necessary.—It is necessary for any corporation or company desiring to lay down a tram line to obtain permission to do so from either Parliament or the Light Railways Commissioners. Plans, showing the routes over which it is proposed to run cars, and the proposed position of the track on the roadway, must accompany the application for permission to construct the tramway. The plans must also show the lengths of single and double track, and the road widths and levels, any places where the rails for a distance of 30 feet or more are less than 9 feet 6 inches from the kerb line being marked as narrow places. These plans then form the working plans of the construction work so far as the position of the track is concerned.

In laying double track, it is not always possible to put both tracks down at the same time, owing to the necessity for keeping the road open for street traffic. In this case one track is completed first and thrown open for traffic while the other track is being constructed. Under the Tramways Act of 1870 the tramway authority must not, without the permission of the road authority, open at one time a greater length than 100 yards in any road which does not exceed $\frac{1}{4}$ mile in length, and in the case of any road exceeding this length a space of $\frac{1}{4}$ mile must be left between the openings. In no case is any part of the roadway to be left open for construction work for a greater period than 4 weeks.

PAVING

50. Types of Paving.—As the tramway authorities have to maintain the paving of the street between the outer rails and for a distance of 18 inches beyond the outer rails, the question of paving is a most important one. This maintenance is one of the hardships imposed on tramway authorities, who have thereby to pay for the cost of paving which is worn down by the ordinary street traffic.

The chief types of paving are (*a*) granite setts, (*b*) wood blocks, (*c*) macadam, (*d*) tar macadam, and (*e*) asphalt.

51. Size of Excavation.—The width of the excavation required for any of the types of paving depends on whether single or double track is used. For single track the width is as follows . Gauge of the track plus twice the width of the rail tread plus 36 inches, the last item being the two 18-inch strips of roadway outside the rails. For double track, the necessary width is double the gauge of the track plus 4 times the width of one rail tread plus the width between tracks plus 36 inches. The depth of the excavation will be the depth of the rail, usually $6\frac{1}{2}$ or 7 inches, plus the depth of the concrete foundation, which will not be less than 6 inches.

When a tram line is laid on country roads where, owing to the small amount of traffic, it is necessary to keep the construction costs as small as possible, the concrete is laid only underneath each rail. The usual width of concrete is 18 inches, so that the excavation necessary for a single track would be two trenches 18 inches wide and about 13 inches deep, and also narrow excavations from rail to rail for the tie-bars and electrical connections. In cold climates where the ground is frozen it is advisable to put in a sub-foundation of broken stone below the concrete. With light cars this method of construction is cheap and satisfactory. Where the lines run over private right of way, the rails may be carried on wooden sleepers, as in railway practice.

52. Track Paving With Granite Setts.—The most satisfactory paving, from the tramway engineer's point of view, is granite setts, as the wear on them is small. Fig. 35 shows the foundations and granite-sett paving for a single track. The concrete foundation, composed of 6 parts by measure of ballast to 1 of cement, is shown at *a* ; *b* is the bedding for the granite setts, consisting of cement mortar or sand and cement ; and *c* is the granite paving. After the excavation has been completed, the rails are placed in position, with all tie-bars fish-plates, anchors, and electrical connections, if required. The rails are then levelled by packing them into position with wood packing pieces, and the concrete is laid and tamped firmly into position under

the rails. When the concrete has set, the bedding for the setts is laid, and the setts are placed in position and stamped down while the bedding is still soft. The paving is finished off by filling the interstices between the blocks for half their depth with

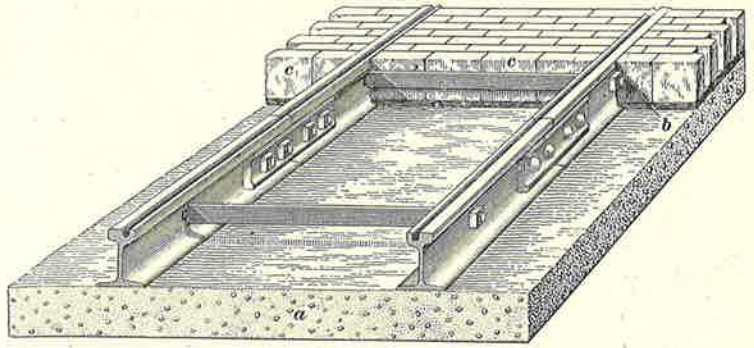


FIG. 35

bitumen and pitch oil, and completing the filling with cement. In some instances, the concrete foundation is put down first, and after it has set the rails are laid and levelled.

53. A section of a double track, which is lettered similarly to Fig. 35, is shown in Fig. 36. The cement filling, or *parging*, as it is called, that is used to fill the space between the rail web and the granite setts *c*, is shown at *d*. The curve, or camber, which is given to the surface of the road, in order that water shall flow to the gutters at the kerb, is also clearly shown.

54. Track Paving With Wood Blocks.—In some towns setts are objected to owing to the noise made by the street traffic in passing over them, and in order to reduce this noise wood blocks are put down. These blocks are sometimes made of soft wood thoroughly impregnated with creosote, but for tramway work the most satisfactory results have been obtained from blocks of a hard Australian wood, called *jarrah*. The blocks are commonly 9 inches long, $4\frac{1}{2}$ inches deep, and 3 inches wide, and are laid with the grain of the wood vertical. The concrete foundation of the track is covered over with a mixture of sharp sand and cement in the proportion of 2 to 1, and carefully surfaced up to give the

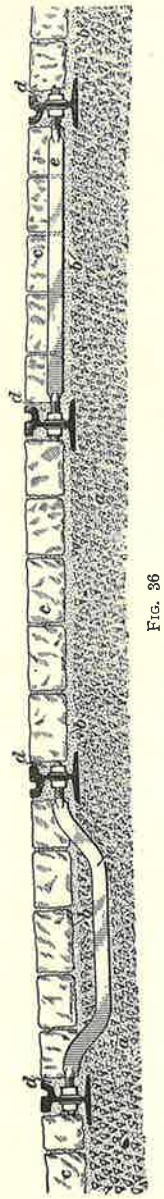


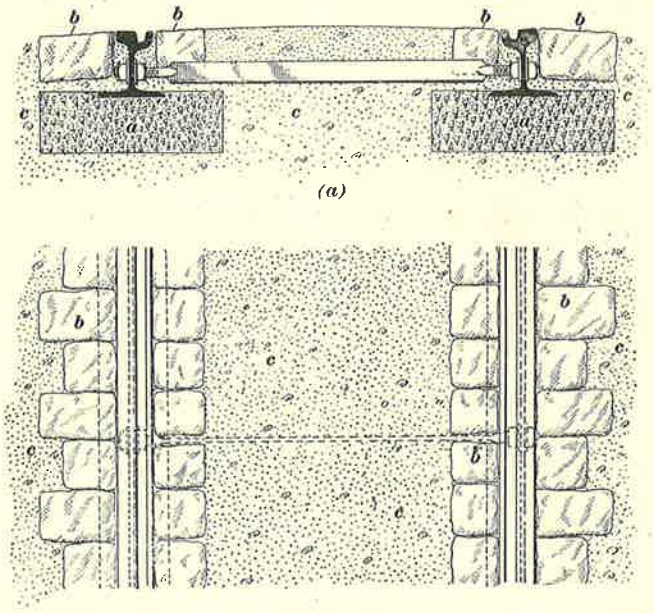
FIG. 36

right camber to the road. The blocks are often dipped in pitch before being placed in position, and are grouted from half to three-quarters of the way up with pitch or mastic asphalt, and finished off with a grouting of sand and cement. A special tie-bar is used, shaped as at *e*, Fig. 36, so as not to interfere with the paving blocks. With granite setts these special tie-bars are not necessary, as the bars can always be worked into the joints; in the case of close-fitting wood blocks, either the method shown would be adopted, or the blocks would be cut where necessary, to allow an ordinary tie-bar to be used. When wood blocks are used in a macadam roadway, it is difficult to make a satisfactory joint between the blocks and the macadam. One method which has been adopted is to lay the wood paving to a width of 14 inches beyond the outside rails, the remaining 4 inches of the margin being made up by granite setts 4 inches wide, laid edgewise. The most satisfactory method is to make the margin entirely of setts, the wood paving only being between the outside rails.

55. Track Paving on Macadam Roads.—As has been already mentioned, the rails in country districts are sometimes laid on a longitudinal sleeper of concrete to save the expense of excavating the whole width between the rails. The road is usually of macadam, and this is not disturbed more than the rail excavations necessitate. Macadam is the name applied to the ordinary road surface of broken stone and sand rolled smooth. To make a lasting joint between the rail and the macadam it is found advisable to place a row of granite setts on either side of the rail, the inside setts being laid longitudinally and the outside setts transversely, a long sett and a

short one alternately. This construction is shown in Fig. 37 (*a*) and (*b*), where the concrete foundation is lettered *a*, the granite setts *b*, and the macadam *c*.

56. Track Paving With Tar Macadam and Asphalt.—The paving material known as tar macadam has only recently been used. It consists of broken stone, or furnace slag, mixed with a tar compound; this is laid and rolled like ordinary macadam.



(*a*)

(*b*)

FIG. 37

Next to the track rails is laid a single course of granite setts in the same way as described in the preceding article. The advantage of tar macadam paving is the absence of dust.

Where asphalt paving is used on tramway tracks, the concrete is carried to within an inch of the rail-tread level and a thin layer of asphalt is rolled on top. This construction gives an exceedingly smooth and dust-free surface, but is only suitable where the road traffic is light.

ELECTRICAL CONSIDERATIONS

RESISTANCE OF TRACK AND CONDUCTOR RAILS

57. Resistance of Track Rails.—Since, in most electric railways, the track is used as one side of the circuit, it is important to know the electrical resistance of steel. The resistance of mild steel varies greatly with its composition; the harder the steel, the higher is the resistance. Track rails are selected for their wearing qualities; hence, a certain degree of hardness is essential; but where a rail is used simply as a working conductor, as in conduit systems, it can often be made of softer steel, because the only wear to which it is subjected is that of the collecting shoes.

Extended tests made on specimens of rails obtained from different sources show specific electrical resistances varying from 6·4 to 13·2 times that of copper. A fine grade of Swedish wrought iron showed a resistance of about 6 times that of copper.

In making calculations regarding track resistance, it has often been assumed that steel ordinarily used in track rails has a specific resistance of 7 times that of copper. Tests show, however, that in most cases the average specific resistance is much higher than this, a value of 10 times the resistance of copper being more nearly in accordance with the facts; this value will therefore be used in the ensuing formulæ.

58. Steel for Conductor Rails.—In cases where the cars are supplied with current from special conductor rails, as in conduit systems, the rails are generally rolled from special soft steel of higher conductivity than that used for the track rails, as mentioned before. Rails rolled from this special steel cost somewhat more than track rails, though tests show that, by properly limiting the impurities in the steel, there is no difficulty in securing a composition which can be made without greatly increasing the cost, and which will have a resistance of not more than 8 times that of copper. The element having the greatest effect on the resistance is manganese, and if the percentage of this is kept down, the other impurities can be present in a

considerable amount without causing a very high resistance. Chemically pure iron has a resistance approximately 4·5 times that of copper, and comparatively small percentages of impurities increase the resistance in a marked degree. Pure iron, even if it could be obtained at reasonable cost, would not be suitable for conductor rails, because it would not be hard enough to stand the wear of the collecting shoes. At the same time, if a conductor rail is made with percentages of carbon and manganese lower than ordinarily used, the conductivity can be improved. The following composition is recommended as giving a resistance not exceeding 8 times that of copper: Carbon not to exceed ·15 per cent.; manganese not to exceed ·30 per cent.; phosphorus not to exceed ·06 per cent.; sulphur not to exceed ·06 per cent.; and silicon not to exceed ·05 per cent.

59. Formulæ for Rail Resistance.—The resistance of 1 yard of copper 1 square inch in cross-section, at 25° C., is ·000025. The specific resistance of steel is taken as being 10 times that of copper.

The resistance of 1 yard of steel 1 square inch in cross-section is, from the foregoing, ·00025 ohm. The resistance varies inversely as the cross-section, and therefore inversely as the weight, as the cross-section, in square inches, is equivalent to the weight divided by 10.

Let R_y = resistance, in ohms, per yard of rail;
W_y = weight of rail, in pounds, per yard.

Then,
$$R_y = \frac{\cdot 00025}{\frac{W_y}{10}} = \frac{\cdot 0025}{W_y} \qquad (1)$$

Rule I.—*The resistance, in ohms, of 1 yard of steel rail is equal to ·0025 divided by the weight, in pounds, per yard.*

Sometimes it is more convenient to have the resistance expressed in terms of 1,000 feet of rail. Since 1,000 feet $= \frac{1000}{3}$ yards,

$$R_l = \frac{\cdot 0025 \times \frac{1000}{3}}{W_y} = \frac{\cdot 833}{W_y} \qquad (2)$$

Rule II.—*The resistance, in ohms, per 1,000 feet of steel rail is equal to ·833 divided by the weight, in pounds, per yard.*

If the resistance per mile is desired, the formula becomes

$$R_m = \frac{\cdot 0025 \times 1{,}760}{W_y} = \frac{4 \cdot 4}{W_y} \qquad (3)$$

Rule III.—*The resistance, in ohms, per mile of steel rail is equal to 4·4 divided by the weight, in pounds, per yard.*

60. In the case of a single track, there are two rails in parallel; hence, the resistance for each unit length of track, two rails, will be one-half that given by the preceding formulæ. For a double-track road, four rails in parallel, the resistance would be one-fourth that given by the formulæ.

With a track well jointed there is no reason why the resistance of 3 feet of rail including a joint should not be as low as that of 3 feet of the solid rail. Hence, for first-class construction, it is permissible to take the resistance calculated from the above formulæ as representing the actual track resistance, without the necessity of adding anything for extra resistance due to joints. If provision is not made for good connection at the joints, the values given by the formulæ will be exceeded by an amount depending on the resistance of the joints.

EXAMPLE.—Calculate the resistance of a 3-mile length of single track consisting of two rails in parallel, each weighing 100 pounds per yard.

SOLUTION.—The resistance may be found from formula **3**, Art. **59**. $W_y = 100$; hence, $R_m = \frac{4 \cdot 4}{100} = \cdot 044$ ohm, and the resistance of 3 mi. of single rail will be $\cdot 044 \times 3 = \cdot 132$ ohm. The two rails being in parallel, the resistance of the track will be $\cdot 132 \div 2 = \cdot 066$ ohm. Ans.

61. For a special conductor rail, with a resistance 8 times that of copper, the formulæ become

$$R_y = \frac{\cdot 002}{W_y} \qquad (1)$$

$$R_l = \frac{\cdot 666}{W_y} \qquad (2)$$

$$R_m = \frac{3 \cdot 52}{W_y} \qquad (3)$$

These formulæ may be used for calculating the resistance of supply and return conductor rails, but will give results too small for ordinary track rails.

RESISTANCE OF WELDED JOINTS

62. Resistance of Cast-Welded Joints.—The resistance of the Falk cast-welded joint compared with that of an equal length of solid rail depends to some extent on the amount of iron used. In some cases the joint resistance may be somewhat higher than that of a corresponding length of solid rail, while in others numerous tests have shown that the resistance is as low or even lower, than that of the rail. The comparative resistances of 3 feet of rail with and without joints, and the number of feet of solid rail having the same resistance as the joint itself, are given in Table VI for a rail weighing 85 pounds per yard.

TABLE VI

RESISTANCE OF CAST-WELDED RAIL JOINTS

Joint Number	Resistance of 3 Feet of Rail Containing Joint Ohm	Resistance of 3 Feet of Solid Rail Ohm	Number of Feet of Solid Rail Having the Same Resistance as Joint Itself
1	·0000468	·0000451	·11307
2	·0000411	·0000239	2·15981
3	·0000275	·0000251	·28686
4	·0000307	·0000306	·00981
5	·0000342	·0000297	·45456
6	·0000291	·0000308	—·16557
7	·0000342	·0000306	·35295
8	·0000306	·0000231	·97404

The average of the values for the equivalent lengths of rail given in the last column of the preceding table is ·52319 foot, or ·5232 foot, approximately. By using this average value for the length of rail having a resistance equal to that of a joint, the equivalent length of solid rail may be calculated.

Let l = length of rail, in feet;
n = number of joints;
l_e = equivalent length of solid rail.

Then, $$l_e = l + \cdot 5232\, n$$

If the equivalent length is known, the resistance may be determined by means of one of the formulæ of Art. **59.**

63. Resistance of Electrically Welded Joints.—Tests show that the resistance of a length of rail with an electrically welded joint is generally considerably less than that of an equal length of solid rail. Table VII shows the resistances of 3 feet of rail with and without joints, and also the length of rail having the same resistance as the joint. The rail considered has a weight of 67 pounds per yard.

TABLE VII

RESISTANCE OF ELECTRICALLY WELDED RAIL JOINTS

Joint Number	Resistance of 3 Feet of Rail Containing Joint Ohm	Resistance of 3 Feet of Solid Rail Ohm	Number of Feet of Solid Rail Having the Same Resistance as Joint Itself
1	·00002966	·00004081	—·81963
2	·00002916	·00003927	—·77232
3	·00003111	·00004076	—·71025
4	·00002971	·00003583	—·51243
5	·00002850	·00002621	—·63876
6	·00002893	·00004071	—·86808
7	·00002748	·00003671	—·75429
8	·00003251	·00003951	—·53151

As the resistance of a length of rail including a joint is less than an equal length without a joint, the resistance of the joint itself is equal to a negative length of rail, and therefore the minus sign is used in the table. The average of the values given is — ·7009 feet; this means that the equivalent length of rail is reduced by ·7009 feet for every joint it contains. Then, for electrically welded joints, the formula given in Art. **62** becomes

$$l_e = l - \cdot 7009\, n$$

64. Resistance of Thermit-Welded Joints.—The resistance of the thermit joint depends, as does that of the cast-welded joint,

on the amount of iron used in the weld. The resistances of 3 feet of rail with and without thermit joints are shown in Table VIII for a rail weighing 80 pounds per yard, from which it will be seen that the resistance of the rail with the joint is somewhat higher than that of the solid rail.

TABLE VIII

RESISTANCE OF THERMIT-WELDED RAIL JOINTS

Joint Number	Resistance of 3 Feet of Rail Containing Joint Ohm	Resistance of 3 Feet of Solid Rail Ohm	Number of Feet of Solid Rail Having the Same Resistance as Joint Itself
1	·0000356	·0000321	·32712
2	·0000347	·0000293	·55293
3	·0000377	·0000316	·57912
4	·0000369	·0000292	·79107
5	·0000365	·0000276	·96741
6	·0000306	·0000311	—·04821
7	·0000359	·0000266	1·04889

The average of the values in the last column of the table is ·6026 foot, approximately. As in the previous case, the equivalent length may be determined by adding a length to the measured length of rail to make up for the resistance of the joints. Using the average given in the table, the formula given in Art. **62** becomes, for thermit-welded joints,

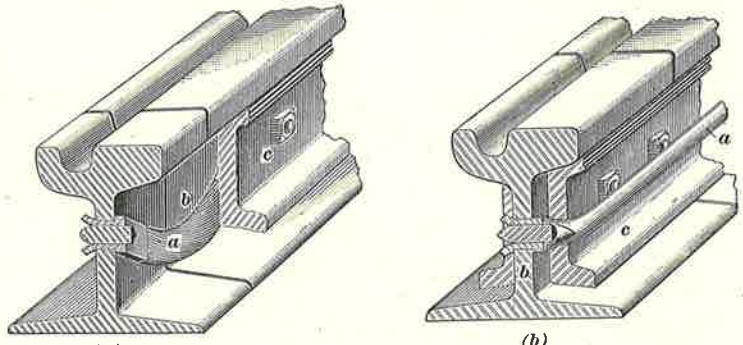
$$l_e = l + \cdot 6026\, n$$

RAIL BONDS

65. Necessity for Bonds.—When the track rails are used to carry the return current and are joined by means of ordinary fish-plates, these must be supplemented by connections, usually of copper, called **rail bonds,** that will carry the current from rail to rail. These rail bonds consist of copper conductors attached to the rails on each side of a joint in such a manner as to make

a very good contact. The fish-plates cannot be depended on to carry the current, because they soon become loose or rusty and offer a high resistance. Joints of the cast-welded or thermit types are also often bonded, in order to ensure electrical continuity of the rail in case of failure of the joint. A great many varieties of rail bond are in use, so that it will be possible to describe here only a few typical examples. No matter what type is used, it must always be remembered that, if a joint is mechanically poor, the continual movement and pounding will sooner or later decrease the efficiency of the bond. It is highly important, therefore, that the joints be kept in good condition. If a track is poorly bonded, there will be a continual loss of power due to the resistance at the joints, the voltage supplied to the car motors will be low, and the speed will be correspondingly reduced. Also, if the return circuit is poor, current will come back to the generating station through neighbouring pipes instead of through the track rails, and trouble on account of electrolysis will result. The maximum drop of voltage allowed by the Board of Trade is, on this account, limited to 7 volts. Bonds are also used for connecting up conductor rails in conduit systems and on electric railways.

66. Classification of Bonds.—Rail bonds may, for convenience, be divided into two general classes: *protected* and *unprotected*.



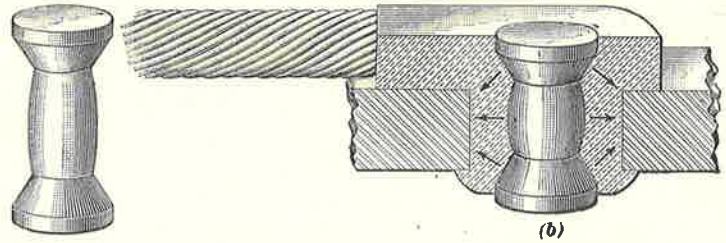
(a) (b)

FIG. 38

Protected bonds are so called because they are placed in the space between the fish-plate and the web of the rail, as shown in

Fig. 38 (*a*), where the bond *a* is attached to the rail web *b* on both sides of the joint and protected by the fish-plate *c*. **Unprotected bonds** span the fish-plate, as shown in Fig. 38 (*b*), where the bond *a* is connected to the web *b* on each side of the fish-plate *c*.

67. Construction and Method of Connecting Bonds.—Bonds of the protected type are used in cases where there is sufficient space for them between the fish-plate and the rail web, as they may be made considerably shorter, and therefore less expensive, than the unprotected type; on the other hand, bonds that are less than 6 inches in length are more liable to give trouble from breakage than longer bonds. The method of making contact between the bond and the web of the rail is a matter requiring careful consideration, and many methods are in use. It is essential that



(a) (b)

FIG. 39

there shall be no possibility of corrosion due to moisture between the terminal and the rail, and that vibration shall not be able to loosen the connection. The bond shown in Fig. 39 (*a*) and (*b*) is made by casting copper terminals on a stranded copper conductor. The copper is cast round an iron plug of the form shown in Fig. 39 (*a*), and after the terminal has been fitted in the web of the rail, the plug is compressed to the form shown in (*b*), thus forcing the metal out against the wall of the hole, as indicated by the arrows, and providing a very firm contact between the terminal and rail. Bonds consisting of thin copper strips soldered together at the ends so as to form solid terminals, which are attached to the rail by soldering, have been experimented with, but are unsatisfactory, as they corrode when they are in contact with damp earth.

68. A protected bond of the *double-loop type*, shaped so as to give flexibility and at the same time allow openings for the fish-

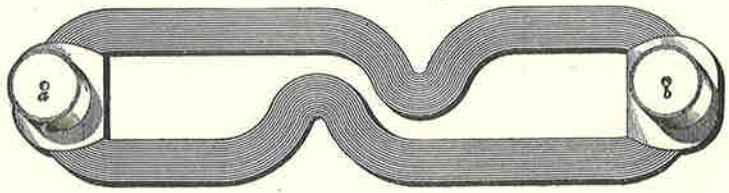


FIG. 40

plate bolts, is shown in Fig. 40. The bond is made of thin copper strips on which copper terminals *a*, *b* have been cast. After these terminals have been passed through the holes in the rail web, they are compressed by a special screw compressor that forces the metal out sidewise, as shown in Fig. 41 (*a*), (*b*), and (*c*). In view (*a*) the copper terminal *a* is shown in position in the rail web *b*, one jaw of the screw compressor being shown at *c*. In view (*b*), the terminal *a* is shown half compressed, and it will be seen that the copper of the terminal is being forced outwards into contact with the steel of the rail web *b*. View (*c*) shows the completed contact; the terminal *a* completely fills the hole in the web *b*, and also forms a flange which holds the bond firmly in position.

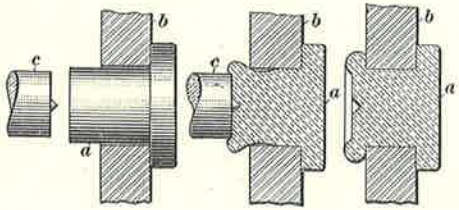


FIG. 41

69. The construction of the screw compressor used for expanding the copper terminals into intimate contact with the rail web is shown in Fig. 42. The compressor consists of a strong steel frame *a* furnished with a screwed steel tube *b*, which can be turned, and thus caused to travel backwards or forwards through the boss *c* of the frame, by means of the hand wheel *d* and nut *e*. The inside of the tube *b* is also provided with a screw thread, in which runs a screwed steel rod, one end *f* of

which carries a point and is used for expanding the terminals, and the other end is furnished with a square head *g*, in order that the whole rod may be screwed forwards by means of a wrench. When fixing the bond, the hole in the rail web is made thoroughly clean and bright by means of a round file or a reamer, and the bond terminal is also made clean and bright. The terminal is then inserted in the rail web, and the compressor placed over the rail and bond with the jaw *h* against the flat part of the bond. The inner screw is then run forwards until the point of the rod strikes into the indenture in the end or face of the terminal; this centres the machine and ensures a uniform pressure on the terminal. The outer screw is next drawn up with the hand wheel until it reaches the rail web and is firmly set by means of the wrench, thus holding the compressor rigidly and drawing the bond home. The inner screw is then moved forwards with the wrench to compress the terminal, the forward movement being continued until the terminal is as shown in Fig. 41 (*c*).

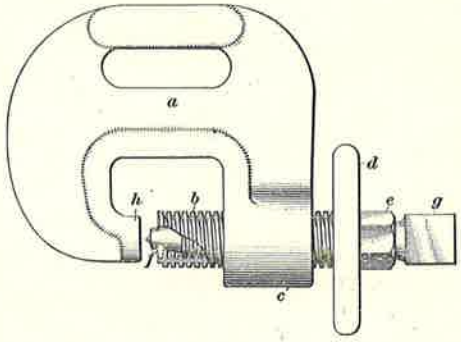


FIG. 42

70. Another type of rail bond which is much used for all classes of work is shown in Fig. 43, the flexible protected type being shown in view (*a*), and the solid unprotected type, for spanning over the fish-plate, in view (*b*). These bonds are connected to the rail in the following way: The holes in the rails and bond terminals are made thoroughly clean and bright. The terminal is then inserted in the hole in the rail web, and the lower end is spread over on the rail with a hammer and punch. A steel pin is then driven into the hole in the bond, expanding the metal of the terminal into good contact with the rail web. The completed joint is shown in Fig. 43 (*a*), in which *a* is the

rail web, *b* the bond terminal spread over by the punch at *c*, and *d* is the steel pin. This type of bond is made in a great variety of shapes suitable for all purposes.

71. Electrically Welded Bonds.—An exceedingly quick and effectual method of attaching bonds to the rails has been brought out by the Forest City Electric Company. This consists in welding the ends of the bond to the rail by means of an alternating current of about 2,000 amperes at a pressure of 5 volts. The current is obtained by taking about 23 amperes, direct current, at 500 volts, from the trolley wire and converting it to alternating current at the required pressure by passing it

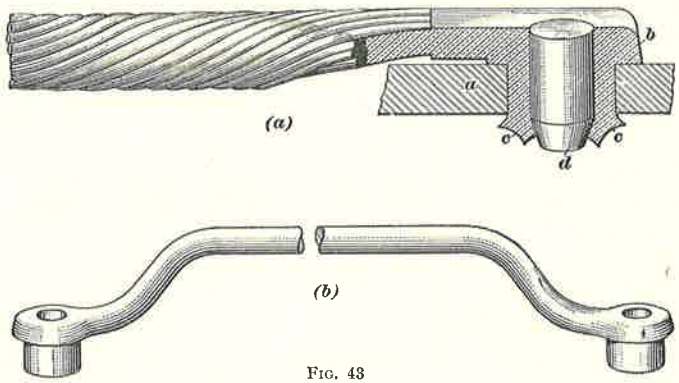


FIG. 43

through a rotary converter and transformer. The equipment somewhat resembles that used for electrical rail welding, but as the current required for bond welding is so much smaller, the transformer and clamping terminals are separate, one transformer usually supplying two sets of clamping terminals.

72. The appearance of the clamping device in position for making a weld is shown in Fig. 44. The two clamp terminals are shown at *a* and *b*, the terminal *a* being merely a copper block and terminal *b* carrying a block of carbon *c*. When in position, terminal *a* makes contact with the rail web, and the end of the bond *d* is held against the other side of the rail web by the carbon block *c*. The current is conveyed to the terminals by

the heavy cables *e*, *e*, and the pressure on the terminals is controlled by the screw handles *f*, *f*. When the current is turned on, it passes from one terminal to the other by way of the bond and rail, making the carbon block *c* incandescent. The combination of the great current density at the surface of the web of the rail where it is in contact with the bond terminal, and the incandescent carbon pressing the copper bond terminal against this surface, quickly generates sufficient heat at exactly the point where it is required to produce a weld. The time required to make a weld is from 45 to 60 seconds, depending on conditions. With bonds of this type there is no danger of the contact deteriorating through corrosion, and the operation of bonding can be performed quickly. It is essential, however, that both sides of the rail web and the bond terminal should be clean and bright before the bond is placed in position. The same company also supply outfits for welding bonds by pouring molten copper over the contact point of bond and rail, but this method is more difficult to carry out than the electrical one.

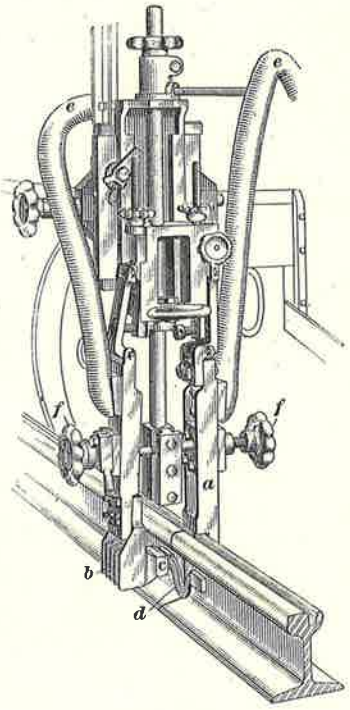


FIG. 44

73. Plastic Bonds.—A type of bond which has been used to some extent in America is known as the **plastic bond.** It consists of solid plates of metal pressed firmly against the rail web, the contact surfaces being first thoroughly cleaned and coated with copper-mercury amalgam of about the consistency of putty, which adheres to the surfaces and makes a connection of very

low resistance. In some forms of this bond the plates are made of copper, and in others the fish-plates themselves are used when they are of sufficient cross-section to carry the current. A bond of the plastic type is shown in Fig. 45 (*a*). The plastic amalgam *a* is held in a cork case, which is compressed when the fish-plates are bolted together, thus bringing the amalgam into intimate contact with the rail and plate surfaces, which have previously been ground off and amalgamated. The path of the current through the joint is indicated in view (*b*). In all of these amalgamated

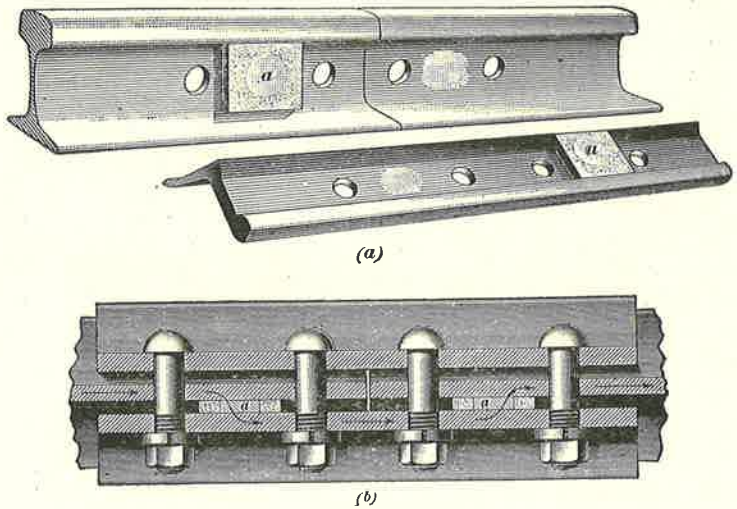


FIG. 45

bonds a slight movement between bond and rail does not impair the contact ; in fact, the amalgam acts, to a certain extent, as a lubricant.

74. Resistance of Bonds.—In making track joints, the aim should be to keep the electrical resistance measured from terminal to terminal of the bond at least as low as the resistance of a corresponding length of rail. It is not difficult to do this with a new joint, but the constant jarring and slight movements to which the bonds are subjected will often cause an increase in resistance when the bonds are not of the welded type. It should

be noted that in Great Britain the sizes of wire bonds are given in Brown & Sharpe gauge (abbreviated B. & S.), and not in Standard wire gauge. The bond holes in the rail web are usually made of smaller diameter than they are ultimately intended to be, so that they can be reamed out to size immediately before the insertion of the bonds, thus ensuring a clean contact surface. The sectional areas of the Brown & Sharpe wires for bonds, and the usual sizes of terminals and holes in the rail web, are given in Table IX.

TABLE IX

SIZES OF BOND WIRES

Size of Wire, Brown & Sharpe Gauge	Sectional Area of Bond Wire Square Inch	Diameter of Terminal and Hole in Rail Web Inch
0000	·1662	$\frac{7}{8}$
000	·1318	$\frac{3}{4}$
00	·1045	$\frac{5}{8}$
0	·0829	$\frac{1}{2}$

75. A No. 000 B. & S. wire has a cross-section of ·1318 square inch, which, assuming the specific resistance of steel to be 10 times that of copper, is equivalent to 1·318 square inches of steel. Two bonds, each 1 foot long, in parallel connecting two 90-pound rails (9 square inches cross-section) will have a resistance equal to that of $\frac{1}{2} \times \frac{9}{1 \cdot 318} = 3 \cdot 41$ feet of rail, neglecting resistance at the bond contacts. The total resistance of a joint is the resistance of the bond in parallel with the resistance that the joint would have without any bond. The channel plates or fish-plates provide some conductivity, but it is very uncertain owing to the variable nature of the contacts between plates and rail. If the work is done carefully, the resistance as measured across 3 feet of rail including the fish-plates and bond can be kept quite as low as the resistance of 3 feet of solid rail. It is necessary, of course, to proportion the bonding according to the weight of the rail ; for example, a 110-pound rail should be bonded heavier than a 90-pound, either by using a heavier bond connection or by providing more bonds at each joint.

TABLE X

LENGTHS OF RAIL EQUAL IN RESISTANCE TO BOND 1 FOOT LONG

British Standard Rail Section Number	Weight of Rail Pounds Per Yard	Cross-Section Square Inches	Cross-Section of Copper Equivalent in Conductivity to Rail Square Inch	Feet of Rail Equal in Resistance to Bond 1 Foot Long Assuming Resistance of Steel = 10 × Resistance of Copper							
				Single No. 0000 B. & S.	Two No. 0000 B. & S. in Parallel	Single No. 000 B. & S.	Two No. 000 B. & S. in Parallel	Single No. 00 B. & S.	Two No. 00 B. & S. in Parallel	Single No. 0 B. & S.	Two No. 0 B. & S. in Parallel
1	90	9	·9	5·41	2·71	6·83	3·41	8·61	4·31	10·86	5·43
1c	96	9·6	·96	5·78	2·89	7·28	3·64	9·19	4·6	11·58	5·79
2	95	9·5	·95	5·72	2·86	7·21	3·61	9·09	4·55	11·46	5·73
2c	101	10·1	·101	6·08	3·04	7·66	3·84	9·67	4·84	12·18	6·09
3	100	10·0	·100	6·02	3·01	7·59	3·9	9·57	4·79	12·06	6·03
3c	106	10·6	·106	6·38	3·19	8·04	4·02	10·14	5·07	12·79	6·40
4	105	10·5	·105	6·32	3·16	7·97	3·99	10·05	5·03	12·67	6·34
4c	111	11·1	·111	6·68	3·34	8·42	4·21	10·62	5·31	13·39	6·70
5	110	11·0	·110	6·62	3·31	8·35	4·18	10·53	5·27	13·27	6·64
5c	116	11·6	·116	6·98	3·49	8·80	4·40	11·10	5·55	13·99	7·00

Table X shows the lengths of rail that are equal in resistance to wire bonds of various sizes, Brown & Sharpe gauge, 1 foot long. Thus, if a 95-pound rail is bonded with two No. 0000 bonds, each 1 foot long, the resistance of the bonds is equal to that of 2·86 feet of rail, assuming that the resistance between bonds and rail is negligible and that the specific resistance of steel is 10 times that of copper.

76. Cross-Bonding.—It is necessary to cross-bond or connect the two rails of the track together at certain intervals so that a break in one or more joints may not seriously impair the conductivity of the return circuit. For example, consider a single-track road where the two rails are bonded throughout but not connected to each other. If a break occurs at a given joint, the portion beyond the joint is of no use in aiding as a return for the current, and an additional load is thrown on the other rail. If, however, the rails are cross-connected at intervals, the current can flow round the break and only a small section of the rail is cut out. On double-track roads all four rails should be connected together. Cross-bonding, with No. 0000 B. & S. copper, should be provided every 40 yards between the rails of one track, and every 80 yards between tracks.

Ordinary bonds in special work, such as points and crossings, are liable to work loose owing to the pounding, so that long bonds should be carried round such fittings from rail to rail, in addition to the short bonds between the fittings and the rail.

BOND TESTING

77. Comparative Tests.—No matter how well a track may be bonded, tests should be made frequently to see that the bonds are in good condition. This is especially necessary round special work and where low joints are noticed. It is not necessary to measure the actual resistance of each joint; comparative readings only are required. For a given class of bonding, the resistance of a joint in good condition as compared with a certain length of rail is known, and it is only necessary to measure the resistance of the joint in terms of rail length; any joints

showing an abnormally high resistance can then be investigated. Usually, 3 feet of rail is taken as the standard, and the resistance, measured between two points 18 inches on either side of the joint, is compared with that of 3 feet of rail. For example, the bonding may be such that a joint in good condition has a resistance perhaps slightly over that of 3 feet of rail, and if a test showed that the resistance was more than twice that of 3 feet of rail, the bonding would be considered poor.

78. Drop-of-Potential Test.—The simplest method of testing for poor bonds is by measuring the drop across the joint by means of a millivoltmeter, and comparing this measurement with the drop across 3 feet of rail. If the current has the same value both in the joint and in the length of rail, the resistances are directly proportional to the voltmeter readings. Owing to the low value of the resistances to be measured, it is necessary to use a low-reading voltmeter, such as a millivoltmeter, to get readings with a reasonably small current in the rails.

Let E_j = drop across 1 yard of rail including joint, in millivolts;
E_r = drop across 1 yard of solid rail, in millivolts;
R_j = resistance of 1 yard of rail and joint, in ohms;
R_r = resistance of 1 yard of solid rail, in ohms.

Then,
$$\frac{E_j}{E_r} = \frac{R_j}{R_r}$$

Thus, in order to determine the ratio of the resistance of a length of rail including a joint to the resistance of an equal length of solid rail, it is only necessary to find the ratio of the millivoltmeter readings in the two cases, care being taken that the current flowing is constant in value.

79. Siemens Bond Tester.—It is usually necessary to make tests of bonds while cars are actually in operation on the system. In this case the current returning along the rails from the cars produces the voltage drop. It would not be satisfactory, however, to take the drop across the joint and then that across 3 feet of rail, because the current in the rail varies as cars are started and stopped, and might not be the same for the two readings. One method of overcoming this difficulty, used in the

Siemens rail-joint tester, is to use a differential millivoltmeter. This is an instrument provided with two windings such that, when equal potentials are applied to the terminals of each, the instrument gives no deflection. One of the windings is connected across the joint, and the other across a length of solid rail. The connections and principle of operation of this device are shown in Fig. 46. The contacts a and b, which in practice consist of sharp steel knife-edges, are adjusted and fixed so that the distance between them is approximately equal to the length of a bond. The contact c, which is also a steel knife-edge, is movable. Contacts a and b are connected to one winding d of the differential millivoltmeter, the other winding e of which is connected across the contacts b and c. The two windings are joined at f.

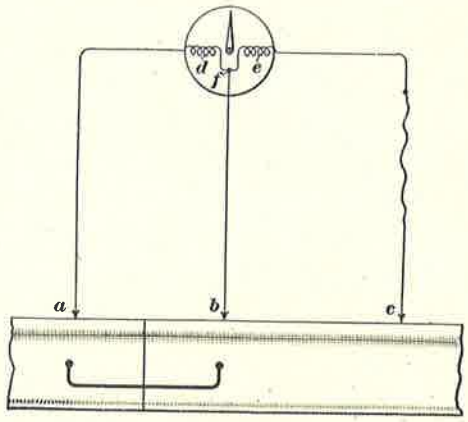


FIG. 46

80. If, with connections as shown in Fig. 46, the position of the contact c is adjusted until the millivoltmeter reads zero, it follows that the drop of potential across $a\,b$ is equal to that across $b\,c$, or, in other words, the resistance of the rail and joint between a and b is equal to that of the length of solid rail between b and c. The position of the point c at which zero reading is obtained is quite unaffected by fluctuations in the current flowing in the rail, because the potentials across d and e are equally affected by any change in current. This method of working gives the equivalent resistance of the joint, in feet of solid rail. If the actual resistance of the joint is required, it can be approximately calculated if the resistance per foot of the solid rail is known. Where a large number of joints are to be tested, the apparatus required for testing is sometimes

installed on a car, which is driven slowly over the track, the tests being made while the car is in motion, and bad joints marked by dropping whitewash on the track.

81. Telephonic Bond Tester.—The method of testing in which a telephone receiver is employed as a detector differs somewhat in principle from the method just described, and possesses the advantage that it can be operated by one person. Fig. 47 shows the method of using the instrument. A bar is provided with

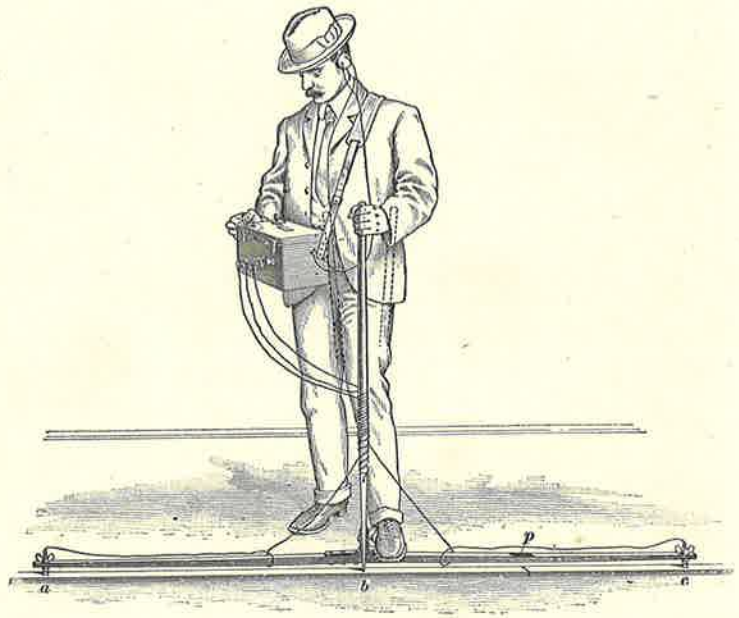


FIG. 47

three hardened-steel knife-edge contacts *a*, *b*, *c*, and a handle at right angles to the bar. When the bar is placed on the rail, as shown, contacts *b*, *c* span 3 feet of rail including the rail joint, plate *p* being placed over the joint, and *a*, *b* span 3 feet of solid rail. The bar is made of tough springy wood, and when the two end contacts rest on the rail, the centre contact is a short distance above the rail, and is pressed down by placing a foot on the bar, as shown. This forces the end contacts out slightly,

and causes the hardened chisel-like contacts to cut through any scale or dirt that may be on the rail, thus making a good connection. In order to make sure that the contact is good, the centre handle can be moved backwards and forwards, as indicated by the dotted lines; the contacts must be sharpened occasionally by means of a small oilstone.

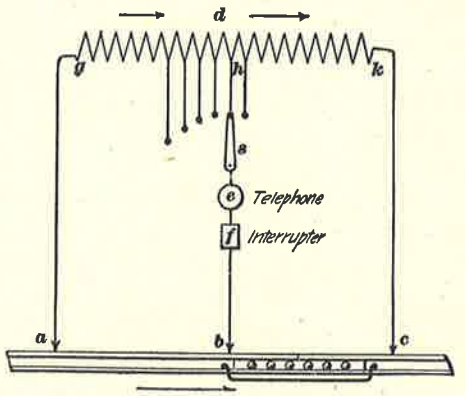


FIG. 48

82. The operation of the instrument will be explained by reference to Fig. 48, where *a*, *b*, *c* represent the three contacts on the rail; *d* is a resistance to which the central contact can be connected at various points by means of a multipoint switch *s*. In series with the middle wire is included a telephone receiver *e* and an interrupter *f*, consisting of a clockwork mechanism that drives a toothed contact wheel, on which presses a small contact spring.

The rail current is represented in Fig. 48 by the heavy arrow; it will be the same in the section of rail *a b* and in the joint *b c*, and will fluctuate according to the number of cars taking current beyond the joint. Resistance *d* being shunted across the rail and joint, part of the current will flow as shown by the small arrows. If the rail section *a b* is equal in resistance to the joint *b c*, and if switch *s* is so placed that resistance *g h* is equal to *h k*, there will be no current in the middle wire and no sound in the telephone, because points *h* and *b* will be at the same potential. If the joint has a greater resistance than the rail section, a balance can be obtained by moving the switch to the left, thus virtually shifting point *h* along the resistance until the voltage drops through the two resistance sections *g h* and *h k* become equal to the voltage drops through the corresponding rail sections *a b* and *b c*.

83. It is hardly possible to obtain such an exact balance that there will be no sound whatever in the telephone, but the point where the sound is a minimum can be quickly found. The interrupter is used to make a clicking sound in the telephone, as the fluctuations in the rail current would not in themselves be regular enough to give an easily detected sound.

In this type of instrument as actually constructed, the contacts of the multipoint switch *s*, Fig. 48, are numbered so as to read off the resistance of the joint in terms of a 3-foot length of rail. Thus, if balance is obtained with the switch on point 1 it indicates that the joint has a resistance equal to 3 feet of rail. If a balance is obtained on 1·5, the joint resistance is equal to 1·5 × 3 or 4·5 feet of rail; if a balance is obtained on 2, the joint resistance is equal to 6 feet of rail. Readings from 1 to 2 are considered as indicating good bonding; readings on points 3 or 4 indicate poor bonding; all readings above 4 indicate very poor bonding. For any given class of bonding, the point at which the switch should give a balance for a good joint is known, and bad joints can therefore be easily detected. Good bonding will never have a resistance greater than twice the same length of rail, and in the better class of work it will not exceed 1 to 1·5 times an equal length of rail; in fact, if proper care is taken, there is no reason why the joint resistance should not be less than that of a 3-foot rail length, particularly if solid rail joints are used.

84. Everett-Edgecumbe Bond Tester.—The connections of a bond tester with which exact balance can be obtained, and in which the telephone and interrupter are replaced by a portable galvanometer, are shown in Fig. 49. Its principle of operation is the same as that of the telephonic bond tester. The contacts *a*, *b*, and *c* consist of sharp-toothed steel blades, which bite into the rail, thus making good contact, and they are attached to a springy wooden bar fitted with a handle *d*. The two end contacts *a* and *c* are connected to the terminals *e*, *f* of a stretched wire. The middle contact *b* is joined through the switch *g* and galvanometer *h* to a movable contact *i*, which travels along the slide wire. This movable contact carries with it a pointer, which

moves over a dial graduated to read the resistance of the joint in terms of feet of solid rail. Exact balance can be obtained with this instrument, because the resistance of that part of the slide wire between *e* and *i* can be made to bear any ratio to the resistance of the part between *i* and *f*. The number of ratios obtainable is infinite, and is not limited, as in the telephonic bond tester, by the number of stops provided on the resistance. It would, however, be easy to replace the resistance and stops in the telephonic device by a slide wire. The galvanometer *h*, Fig. 49, is specially constructed for portability, and is carried, together with the slide wire, in a box attached to a shoulder strap.

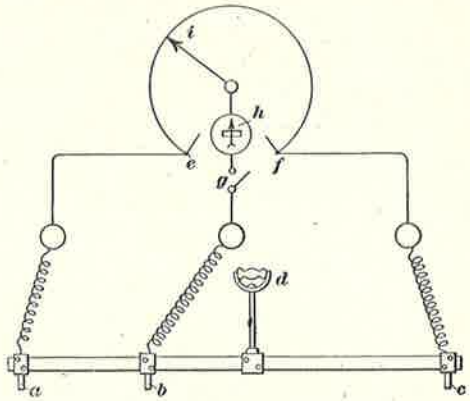


FIG. 49

ELECTROLYSIS

85. General Effects of Electrolysis.—The subject of **electrolysis,** which is here taken to mean the eating away of the rails, underground pipes, or other buried metallic conductors by stray currents from the tramway system, is closely connected with the feeding system, especially with the track-return part of it. When electrolysis was first noticed, a great outcry was raised against the systems with a rail return by gas and water companies, telephone companies, and other corporations owning underground pipes or lead-covered cables.

This led to an investigation of the subject, with the result that stringent regulations were framed by the Board of Trade, limiting the voltage drop in the rails, the effect of which has been to reduce the damage due to the leakage current to a negligible quantity.

86. Elementary Principles.—If the terminals of two iron plates A and B, Fig. 50, which are buried in damp earth, are connected to a direct-current generator, and a current made to flow from A to B through the earth, plate A will be eaten away or pitted, while plate B will not be damaged. This is practically the same electrochemical effect that takes place in electroplating, where metal is taken from a plate, or anode, from which current enters the chemical solution or electrolyte, and deposited on the article to be plated, which is always placed where the current passes out of the solution. The point to notice is that wherever current flows *from* a metal conductor into an electrolyte or damp earth, the conductor is eaten away, provided that the difference of potential between the conductor and the adjacent earth is sufficient to effect the chemical decompositions; but where current flows from the earth *into* the conductor, the latter is not damaged. The rate at which the metal will be eaten away depends on the strength of the current.

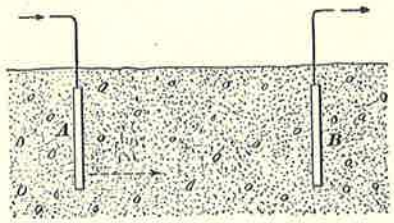


FIG. 50

87. Table XI shows the weight of metal that will, theoretically, be eaten away by 1 ampere flowing steadily for 1 year, for metals likely to be affected by stray underground currents. This table is of interest chiefly because it shows the relative effect of a current on the different metals.

TABLE XI

ELECTROLYTIC EFFECT OF CURRENT ON VARIOUS METALS

Metal	Grammes Per Ampere-Hour	Pounds Per Ampere Per Year
Aluminium	·327	6·31
Copper	1·190	22·97
Iron	1·044	20·15
Lead	3·852	74·34
Tin	2·218	42·71
Zinc	1·216	23·47

88. It does not follow that, in practice, whenever a current of 1 ampere flows for 1 year from a conductor into the ground, the amounts of metal indicated by Table XI will be eaten away. In fact, under some circumstances current may flow from a buried conductor to the ground without eating the metal at all. For example, the elements or compounds liberated by the current may be such that no corroding action takes place on the pipe, or the energy expended per unit area of the pipe surface may not be great enough to decompose the salts in the damp earth. It has also been found in many cases that electrolytic action may take place for a while and then cease, owing to the character of the earth round the conductor having become changed by the decomposition of the salts contained therein and rendered incapable of acting as an electrolyte for further electrolytic action.

89. It should be remembered that underground pipes and conductors may become corroded by the simple chemical action of the salts contained in the earth, and it by no means follows that whenever a conductor or pipe shows signs of pitting the corrosion is due to electrolysis; in fact, there is no sure way of telling simply from the appearance of the pipe to which source the corrosion is due.

In Table XI, it is interesting to note that lead is eaten away more rapidly than any of the other metals there given. Underground lead pipe and the lead sheaths of underground cables are, under like conditions, eaten away much more rapidly than iron pipe. The corrosion never takes place evenly, but in spots, so that the pipe or sheath becomes pitted, and is soon destroyed. However, the general practice now is to run underground cables in earthenware ducts or conduits, which form an insulating medium between the cable sheath and earth, thus preventing electrolysis to a large degree. Wrought-iron pipe is much more susceptible to electrolytic corrosion than cast-iron; with cast iron the impurities in the iron appear to form a kind of scale on the surface that protects the pipe. The harder grades of cast iron, such as chilled iron, seem to be very little affected by electrolysis under ordinary conditions.

90. Electrolysis Due to Tramway Currents.—A diagram showing how electrolysis may occur in connection with an overhead trolley system is given in Fig. 51. Current is supplied to the car *C* by means of the trolley wire *T*. The track *R* under ordinary conditions acts as the conductor for the return current, as indicated by the arrows. If, however, there happens to be a pipe *L*, in the neighbourhood of the track, that offers a ready path for the current, part of the current will leave the rails, as at *I*, enter the pipe, and flow out again at *O* to return to the power station *P*. At *O*, where the current leaves the pipe, electrolytic action will be set up, if the conditions are favourable, and in the course of time holes will be eaten in the pipe. At *I* the current leaves the rails ; hence, they will be eaten away to some extent. If the trolley wire were connected to the negative

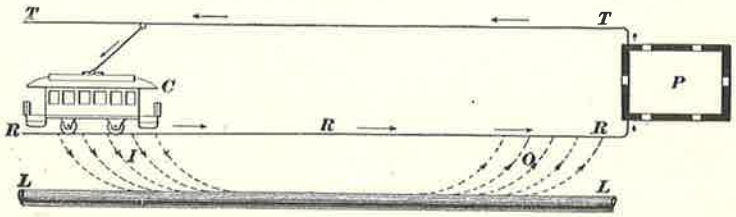


Fig. 51

pole of the generator instead of the positive, the current would flow out through the track, and whatever corrosion occurred on the pipes would take place at points removed from the station and would be scattered over a wide area. On the other hand, with the positive pole connected to the trolley, whatever action takes place on the pipes is confined to districts near the power house. These areas are comparatively small, and measures can be taken to protect them. This is the chief reason why the positive pole of the generator should be connected to the trolley side of the line.

91. With an arrangement of track and pipes such as shown in Fig. 52, the current may leave the rail *r*, enter the pipe *w*, and flow through *w* until a better path presents itself in the shape of the lead-sheathed cable *c*. It then flows along *c* until the track

presents a better path, when it returns to the rail again, as indicated by the arrows. Electrolytic action may occur where the current leaves the rail, the iron pipe, and the lead sheath of the cable.

It will be seen, by referring to Fig. 51, that if the track return is in good condition, there will be little inducement for the current

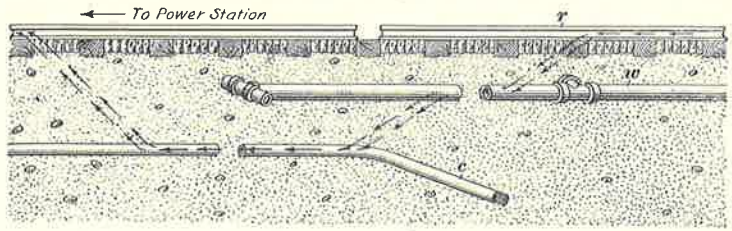


Fig. 52

to leave the track and pass through the intervening earth to come back on the pipes. One of the most effective precautions against electrolysis is thorough rail bonding. Systems in which both go and return conductors are insulated are, of course, free from the liability to cause electrolysis.

92. Prevention of Electrolysis.—The rules laid down by the Board of Trade for the prevention of electrolysis, and the periodic tests which they require to be made to ensure the observance of these rules, have been enumerated elsewhere ; the arrangement of the switchgear necessary for the tests has also been described. The result of these regulations and tests is that the drop of pressure in the rails is limited to 7 volts, that the difference of potential between any pipe or cable sheath and the rail is limited to about $4\frac{1}{2}$ volts if the rail is positive to the pipe, and to about $1\frac{1}{2}$ volts if the pipe is positive to the rail, and that the current returning to the power station through the earth is limited to 2 amperes per mile of single track, or 5 per cent. of the total current output. With regulations such as these, it is found that electrolysis is practically negligible.

93. Negative Feeders.—In order that the drop of pressure in the rails shall not exceed 7 volts, it is necessary to connect them

at intervals to insulated cables, called **negative feeders,** or **return feeders,** which carry part of the current from the rails back to the power station. These cables are of the ordinary type, and are run underground in ducts or conduit ; they are attached to the rails in the same manner as bonds. Fig. 53 shows a method of

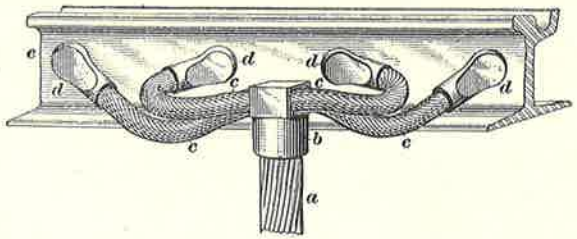


FIG. 53

connecting a negative feeder to the rail. The feeder cable *a* is attached to the copper terminal *b*, into which are fused the flexible conductors *c*. These conductors are cast into the bond terminals *d*, which are attached to the rail web *e* by any of the methods used for making bond connections.

94. Negative Boosters.—In order to reduce the size of the negative feeders required to keep the rail drop within the specified limit, the power-station ends of the feeders are connected to the negative bus-bars through **negative boosters.** These are small direct-current series generators, which are designed to carry the

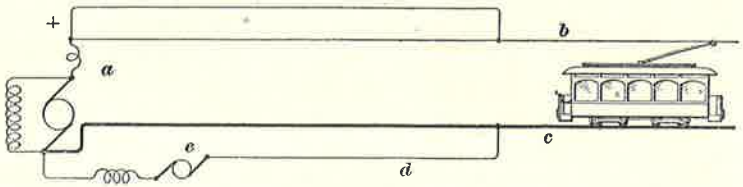


FIG. 54

whole current in the feeder, and to generate a voltage equal to that lost in the feeder, so that it is possible to use a feeder in which there is a fairly large drop in pressure. They are often driven by shunt motors supplied from the main bus-bars. The way in which the feeders and boosters are connected is indicated

in Fig. 54, where *a* is the main compound generator, the positive pole of which is connected to the trolley wire *b*. The rails *c* are connected through the return feeder *d* to the negative terminal of the series-wound negative booster *e*, the positive terminal of which is connected to the negative terminal of the generator *a*.

95. The action of the negative boosters will be made more clear by the consideration of a simple numerical example. Suppose that Fig. 55 represents a tramway system supplying current to a number of cars equally distributed over the whole length of the line. This is equivalent to a load equal to the sum of all the currents taken by the separate cars, this load being situated in the mean position, that is, at *a*, half-way along

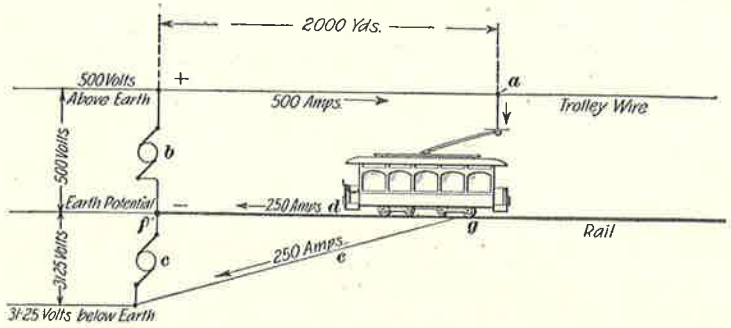


FIG. 55

the line. The current is assumed to be 500 amperes, and *a* is 2,000 yards from the generating station, which contains the main generator *b* and the negative booster *c*. The track *d* is supposed to consist of British Standard No. 2 rails, which, from Table II, have a weight of 95 pounds per yard, and from rule I, Art. **9,** a sectional area of 9·5 square inches.

96. From rule I, Art. **59,** the resistance per yard of rail is $\frac{\cdot 0025}{95} = \cdot 0000263$ ohm. The resistance of 2,000 yards is therefore $2{,}000 \times \cdot 0000263 = \cdot 0526$ ohm. The resistance of 2,000 yards of track, consisting of two rails in parallel, is therefore $\frac{\cdot 0526}{2} = \cdot 0263$ ohm. If there is no negative feeder or

booster, the drop in volts in rails = current × resistance of rails = 500 × ·0263 = 13·15 volts. As this drop exceeds the 7 volts allowed by the Board of Trade, steps must be taken to reduce it to half its present value. There are two methods available for doing this, the first being to use a negative feeder alone, and the second to use a negative feeder in connection with a negative booster. As the drop, and consequently the current in the rails, must be reduced to one-half, the resistance of the negative feeder *e*, Fig. 55, if used without a booster, must be equal to the resistance of the track between *f* and *g* in order that feeder and track may share the current equally. The total sectional area of the two track rails is 2 × 9·5 = 19 square inches. The specific resistance of steel has been taken as 10 times that of copper, so that the sectional area of copper in the feeder, assuming that the feeder is of the same length as the track between *f* and *g*, is $\frac{19}{10}$ = 1·9 square inches. The cost of a feeder with such a large area of copper would be quite prohibitive, and a smaller cable, in conjunction with a negative booster, would be used.

97. The capacity of the negative booster required in the case which has just been outlined would be found in the following way: The current to be carried by the cable is 250 amperes. Assuming that the sectional area of the cable to be used is ·4 square inch, which would carry the current safely without undue rise of temperature, the resistance of 2,000 yards of this cable would be equal to that of 2,000 yards of rail of an area of ·4 × 10 = 4 square inches. The weight of this rail would be 40 pounds per yard, and its resistance per yard would be $\frac{\cdot0025}{40}$ = ·0000625 ohm. The resistance of 2,000 yards of the rail, and therefore of 2,000 yards of cable ·4 square inch in sectional area, would be ·0000625 × 2,000 = ·125 ohm. The drop in pressure along this cable would thus be 250 × ·125 = 31·25 volts. The booster would have to compensate for this drop, with 250 amperes passing through it, and its capacity would therefore be 30 × 250 = 7,500 watts = 7·5 kilowatts.

The duty of the booster is thus to provide the E.M.F. necessary to make the current return along a cable which is of higher resistance than the track. The size of the return cable was assumed in the above example, but would in practice be fixed by the carrying capacity of the cable, and by Kelvin's law, which states that the annual cost of the watts lost in the cable should equal the annual amount of interest on the cost of the cable plus an allowance for depreciation of the cable.